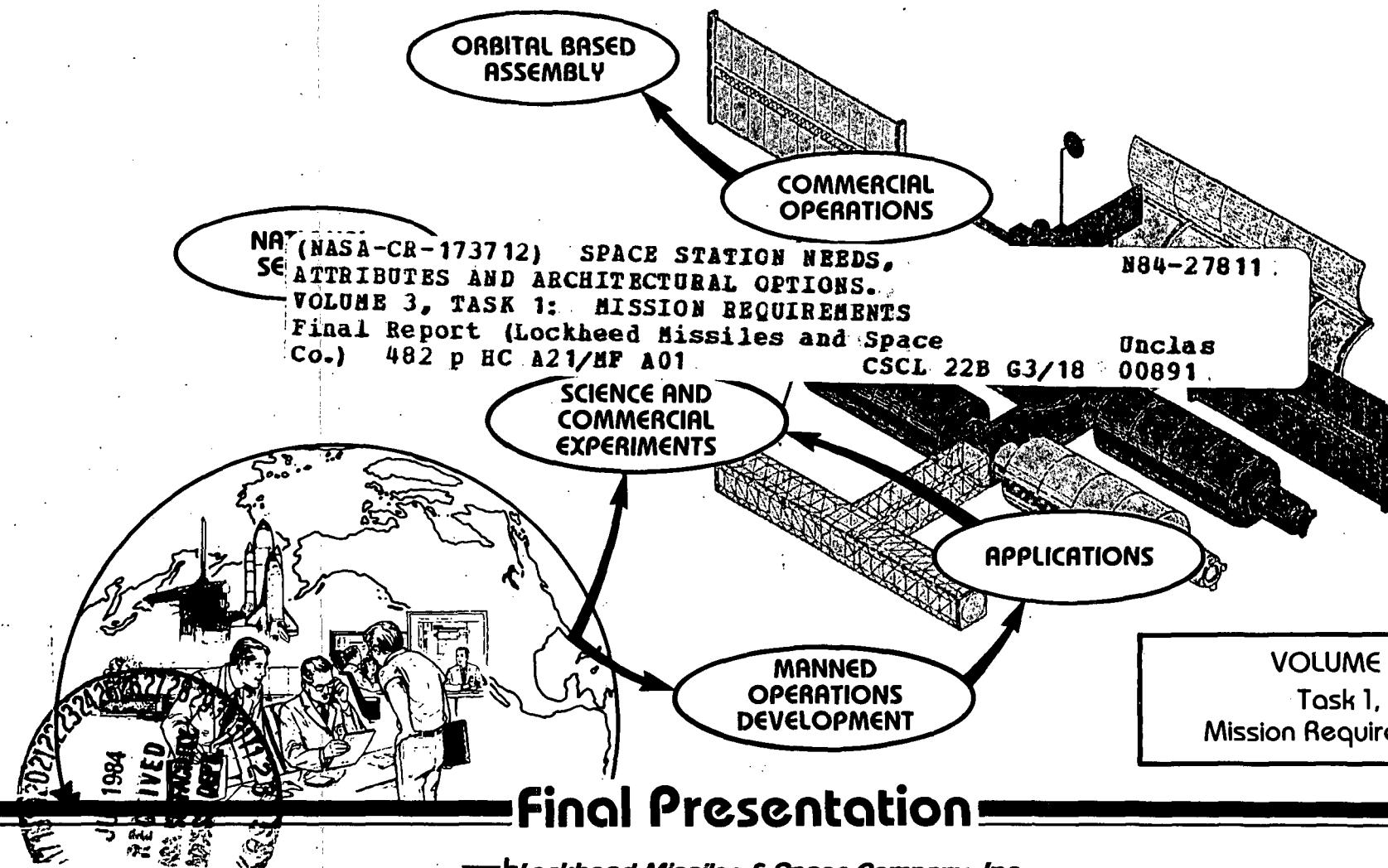


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LMSC-D889718  
5 APRIL 1983



# Space Station Needs, Attributes and Architectural Options



Lockheed Missiles & Space Company, Inc.

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SPRINGFIELD, VA. 22161

N84-27811

SPACE STATION NEEDS, ATTRIBUTES AND ARCHITECTURAL OPTIONS  
VOLUME III, TASK 1: MISSION REQUIREMENTS

Lockheed Missiles and Space Company, Inc.  
Sunnyvale, CA

Apr 83

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**Space Station Needs, Attributes,  
and Architectural Options**

**FINAL PRESENTATION  
CONTRACT NAS3684  
5 APRIL 1983**

**VOLUME III**

**Task 1,**

**Mission Requirements**

**Prepared For**

**NASA Headquarters  
Washington, D.C.**

**Prepared By**

 **Lockheed Missiles & Space Company, Inc.**  
Sunnyvale, California 94088

SPACE STATION STUDY FINAL PRESENTATION

---

This presentation includes a description of the effort performed for and the results from the Space Station Needs, Attributes, and Architectural Options study performed by LMSC for NASA and the DoD, during the period from August 1982 to April 1983. The presentation format is consistent with the contract task breakdown. Supporting analysis date which is to detailed and voluminous to include here will be provided in Attachment 2 as to the contract Final Report.





## FINAL PRESENTATION OUTLINE

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- OVERVIEW
- STUDY ACTIVITY AND STATUS
  - TASK 1 - MISSION REQUIREMENTS (NASA AND DoD)
    - 1.1 USER ALIGNMENT PLAN
    - 1.2 SCIENCE AND APPLICATIONS
    - 1.3 COMMERCIAL
    - 1.4 U.S. NATIONAL SECURITY
    - 1.5 SPACE OPERATIONS
    - 1.6 REQUIREMENTS FROM USER NEEDS
    - 1.7 FOREIGN CONTACTS
  - TASK 2 - MISSION IMPLEMENTATION CONCEPTS
    - 2.1 MISSION SCENARIO ANALYSIS AND ARCHITECTURAL CONCEPTS
    - 2.2 OPERATIONS/FUNCTIONAL ANALYSIS
    - 2.3 MISSION OPERATIONS ARCHITECTURAL DEVELOPMENT
    - 2.4 ARCHITECTURAL ANALYSIS/TRADES
    - 2.5 EVOLUTION
    - 2.6 CONFIGURATION
  - TASK 3 - COST AND PROGRAMMATIC ANALYSIS
    - 3.1 BENEFITS
    - 3.2 COST, SCHEDULE, AND FUNDING
  - TASK 4 - DOD (CLASSIFIED PRESENTATION)
- TECHNOLOGY DEVELOPMENT
- CONCLUSIONS
- RECOMMENDATIONS



# STUDY OVERVIEW

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The Lockheed logo consists of a stylized arrow pointing upwards and to the right, followed by the word "Lockheed" in a bold, italicized, sans-serif font.

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STUDY OBJECTIVES

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Now that the space shuttle is operational, NASA has to be prepared for the next logical step, "Space Station", which will establish man's continuous presence in space. The objectives for this study were formulated to attain the above goal by giving the space station study as broad a support base as possible. Lockheed is dedicated to work with NASA for the attainment of these objectives, throughout the study contract and beyond.

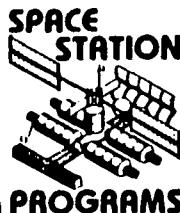
Further objectives of this study were for each contractor to use his own enginuity with a minimum of technical direction from NASA. The reasoning here was to stay away from existing designs, to resist doing detailed design work, but instead to define the fundamental space station system architecture.

Lockheed started from the basic level of setting requirements. Obtaining requirements by means of the actions stipulated in our alignment plan was extremely difficult, which confirmed our initial fears. Other methods (scenarios) were used to trigger potential user inputs which resulted in coverage of all issues with guarded success.

When this study ends a large number of new potential space station users will have been identified. A very strong U. S. national Security Operational Mission has been identified and studied in some depth.

NASA should not let this new found enthusiasm die on the vine. Continuous effort is required to translate these needs into hard requirements.





## STUDY OBJECTIVES

- TO CREATE BROAD BASED USER SUPPORT FOR THE SPACE STATION
- TO GAGE THE "POTENTIAL USER" READINESS FOR SPACE STATION START-UP IN FIVE AREAS
  - (1) SCIENCE
  - (2) APPLICATIONS
  - (3) COMMERCIAL
  - (4) U.S. NATIONAL SECURITY
  - (5) SPACE OPERATIONS
- TO PROVIDE POTENTIAL USERS WITH KNOWLEDGE OF SERVICES AND POTENTIAL BENEFITS OF A SPACE STATION SYSTEM
- TO IDENTIFY AND TO DEFINE USER REQUIREMENTS THAT WILL DRIVE THE SPACE STATION DESIGN
- TO IDENTIFY AND TO CHARACTERIZE SPACE STATION SYSTEM ATTRIBUTES AND CAPABILITIES TO MEET USER REQUIREMENTS
- TO ESTABLISH EVOLUTIONARY ARCHITECTURE FOR DEVELOPMENT, INTEGRATION AND OPERATION OF A SPACE STATION SYSTEM
- TO ESTABLISH COST ESTIMATES FOR EVOLUTIONARY SPACE STATION CONCEPTS, AND SOCIO/ECONOMIC BENEFITS

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LOCKHEED STUDY APPROACH

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The user alignment plan consisted of 3 phases, (1) presentation preparation, (2) making the contacts, and (3) follow-up. Contacts were established through small group presentations, individual company contacts and 2 seminars. Statistical marketing data shows that many contacts have to be made in order to identify one that is worthwhile. Sending a multitude of questionairs to the user community at large has proven insufficient. Lockheed therefore chose the direct and personal contact mode. Data already in existence from NASA and others were placed in a data base for easy accessibility and later use.

When it became apparent that user requirements were few and slow in coming, a number of scenarios was prepared for closer focusing and possible endorsement by potential users.

A space station system evolution was developed based on requirements created, technical capability, and cost of each phase.

With this system evolution in mind a set of architectural concepts was prepared. Options and alternative approaches were investigated and cost estimates were made. We did selectively pare down the existing data base (which contains over 245 missions) by eliminating missions which are not suited for space station-based support. The resulting list of about 90 missions was reviewed with the users to be sure that appropriate selections had been made. We did not attempt to embellish the data contained in the NASA data-base unless (as happened in a very few cases) the user could supply added information. This was done to avoid the impression that these are "new" missions, and thereby give the new data unwarranted authenticity.





## LOCKHEED STUDY APPROACH

- USER ALIGNMENT PLAN HAS BEEN IMPLEMENTED  
(450 VISITS, 320 PEOPLE CONTACTED)
  - SEMINARS, FOLLOW-UP CONTACTS
  - SMALL GROUPS, REPEAT VISITS
  - SINGLE CONTACTS
  - PRESENTATIONS TO SPECIAL INTEREST GROUPS
- EXISTING DATA BANK USED TO DEFINE A LARGE NUMBER OF STATION REQUIREMENTS
- OUR APPROACH WAS TO DEVELOP AND FOCUS ON 10-20 VALID MISSION SCENARIOS WITH MULTIPLE USER CONCURRENCE
- DEFINITION OF ARCHITECTURAL OPTIONS AS THEY ARE INFLUENCED BY COMMUNICATIONS, OPERATIONS, SUB SYSTEM EVOLVABILITY, AND REQUIRED TECHNOLOGY GROWTH.
- DEVELOPMENT OF DETAILED DESIGNS WAS CONSIDERED PREMATURE AND THEREFORE WAS DELIBERATELY AVOIDED
- COSTING OF EVOLUTIONARY CONCEPTS, ALTERNATIVE APPROACHES, AND OPTIONS BASED ON MINIMUM DESIGN DETAILS

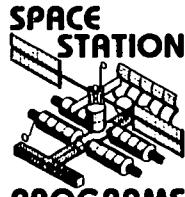
STUDY TEAM

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The study team as presented in the proposal, performed the study tasks as proposed. Special assignments were accomplished by personnel from other disciplines as these needs were identified.

The senior advisory board met 7 times during the contract performance period; our consultants were included in these meetings. Written data exchange agreements were signed with three European companies, Dornier, MBB/ERNO, and GTS.





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## STUDY TEAM

### ADVISORY BOARD

W. R. WRIGHT, VP  
NASA PROG  
M. W. HUNTER, II  
L. W. ACTON  
R. J. HERZBERG  
R. E. McNULTY  
B. G. MORAIS  
J. B. REAGAN

### SPACE STATION PROGRAM

K. FORSBERG  
MANAGER  
D. SMITH  
DEPUTY

### SUBCONTRACTORS

ECON  
ARTHUR D. LITTLE  
VOUGHT

PRODUCT  
DEVELOPMENT  
R. STEGMAN

PROGRAM CONTROLS  
J. K. MARTIN  
APM

USER ALIGNMENT  
TEAM  
F. HEKKING

MISSION  
REQUIREMENTS  
W. JAMES

MISSION  
IMPLEMENTATION  
E. WALLER  
D. GARDNER

COST AND  
PROGRAMMATICS  
C. HOPKINS  
J. SKRATT

SCIENCE AND APPLICATIONS  
(LIFE SCIENCES) - T. OLCOTT  
SCIENCE AND APPLICATIONS  
(PHYSICAL SCIENCES) - R. VONDRAK  
NATIONAL SECURITY - P. SMITH  
COMMERCIAL  
(MATERIAL PROCESSING) - P. GRODZKA  
SPACE OPERATIONS - T. FISHER

DATA EXCHANGE  
AGREEMENTS  
DOMESTIC:  
HAM STANDARD  
IBM  
FOREIGN:  
GTS  
MBB/ERNO  
DORNIER  
SPAR

CONSULTANTS  
H. ASHLEY  
W. HAWKINS  
W. HAYES

TECHNOLOGY  
P. BENE

 Lockheed

STUDY SCHEDULE

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The overall study schedule shows the four overlapping principal study tasks, the dates of review meetings, and the due dates of the draft and final report.

The final review and draft report dates have been moved ahead to 5 April 1983 per the NASA redirection. The final study report is dated 22 April 1983 as originally planned.





LMSC-D889718

## STUDY SCHEDULE

MAJOR MILESTONES	1982				1983			
	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
START OF CONTRACT								
ORIENTATION MEETING	▼	▼						
MID-TERM REVIEW			▼					
FINAL REVIEW AND DRAFT REPORT								
FINAL STUDY REPORT					▼	▼		
<u>TECHNICAL EFFORT</u>								
TASK 1 - MISSION REQUIREMENTS								
	USER CONTACTS							
TASK 2 - MISSION IMPLEMENTATION CONCEPTS								
TASK 3 - COST AND PROGRAMMATIC ANALYSIS								
TASK 4 - DoD TASK								
FINAL STUDY REPORT PREPARATION								

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CONCLUSIONS FROM USER CONTACTS  
SCIENCE AND APPLICATIONS

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A considerable constituency exists for science experiments which can be tended and which will have frequent turnaround and long time on orbit. Application missions can be efficiently developed on a manned space station in an R&D environment and later be converted to free flyers.

We believe strong support for space station will develop in the scientific community once it becomes apparent that shuttle flights will be difficult to schedule for purely science missions and transportation costs for an unmanned platform will be prohibitive if not shared.





## CONCLUSIONS FROM USER CONTACTS SCIENCE AND APPLICATIONS

SPACE STATION WILL BE A BOONE TO SCIENCE AND APPLICATION  
EXPERIMENTS AND OPERATIONS

- MAN TENDED
- LONG TERM OPERATIONS
- FREQUENT ACCESS AND TURNAROUND WITH TRANSPORTATION COST  
SHARED WITH OTHER USERS

CONCLUSIONS FROM USER CONTACTS  
COMMERCIAL

---

Industry remains cautious concerning any significant commitment to commercial use of the space environment. It is apparent the government should support further basic research to substantiate the benefits of using the space environment. (Similar to the early development of communication satellites).

Also essential to use of space is a clarification and reduction in cost of the transportation system. Early experimental use of the space station can be expected if costs are reasonable.





## CONCLUSIONS FROM USER CONTACTS COMMERCIAL

LARGE SCALE INDUSTRY COMMITMENT TO USE OF THE SPACE ENVIRONMENT IS DEPENDENT ON

- COMPLETION OF MORE ADVANCED BASIC RESEARCH
- REDUCED AND BETTER UNDERSTOOD COST OF SPACE OPERATIONS

CONCLUSIONS FROM USER CONTACTS  
NATIONAL DEFENSE

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A strong interest in R&D using a space station is apparent within the DoD.

Several operational missions appear to be of sufficient potential interest to justify proceeding with an early developmental station.





## CONCLUSIONS FROM USER CONTACTS NATIONAL DEFENSE

---

DoD MISSION REQUIREMENTS ARE IN THE EARLY PHASE OF DEFINITION

- RESEARCH AND DEVELOPMENT IS ACCEPTED AS VALID BUT NOT GOVERNING
- SEVERAL OPERATIONAL MISSIONS HAVE ATTRACTED INTEREST
- MAINTENANCE AND SUPPORT MISSIONS ARE DISCERNIBLE

CONCLUSIONS FROM USER CONTACTS  
SPACE OPERATIONS

---

A space station is expected to have a dramatic effect on how the US operates in space but it is clear the station must come first. The spacecraft will be developed to use on-orbit maintenance. Transportation vehicles will evolve which will be space-based and maintained: LEO and GEO spacecraft will become larger and more efficient. Manned operations will become safer.





## **TASK 1—MISSION REQUIREMENTS**

- 1.1 USER ALIGNMENT PLAN**
- 1.2 SCIENCE AND APPLICATIONS**
  - PHYSICAL SCIENCES
  - LIFE SCIENCES
- 1.3 COMMERCIAL**
- 1.4 U.S. NATIONAL SECURITY**
- 1.5 SPACE OPERATIONS**
- 1.6 REQUIREMENTS FROM USER NEEDS**
- 1.7 FOREIGN CONTACTS**





## CONCLUSIONS FROM USER CONTACTS SPACE OPERATIONS

THE ADVENT OF SPACE STATION WILL DRAMATICALLY CHANGE HOW WE OPERATE IN SPACE - SPACE STATION MUST COME FIRST - THEN

- SPACECRAFT WILL BE DESIGNED FOR IN ORBIT MAINTENANCE
- ADVANCED SPACE BASED TRANSFER VEHICLES WILL BE DEVELOPED
- LARGER LEO AND GEO SPACE PLATFORMS WILL BECOME FEASIBLE
- CURRENT OTVs CAN BE USED PENDING DEVELOPMENT OF ADVANCED VEHICLES



## **TASK 1—MISSION REQUIREMENTS**

### **1.1 USER ALIGNMENT PLAN**

### **1.2 SCIENCE AND APPLICATIONS**

- PHYSICAL SCIENCES
- LIFE SCIENCES

### **1.3 COMMERCIAL**

### **1.4 U.S. NATIONAL SECURITY**

### **1.5 SPACE OPERATIONS**

### **1.6 REQUIREMENTS FROM USER NEEDS**

### **1.7 FOREIGN CONTACTS**

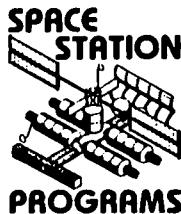


## USER ALIGNMENT PLAN

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The basic plan, which called for small group meetings and personal contacts, was successfully executed. Follow-up contacts were made as part of the planned effort. A total of 320 people were visited (and some revisited) in a series of 420 individual meetings. Two seminars for commercial opportunities were conducted. Specifics about the seminars will be presented in the commercial section of this presentation. A complete listing of the contacts made throughout the study period is presented in Attachment 2, Volume I of the final report.





## USER ALIGNMENT PLAN

- USER ALIGNMENT PLAN SUCCESSFUL  
(420 VISITS, 320 PEOPLE CONTACTED)
  - INITIAL CONTACTS MADE, STRATEGY DEVELOPED
  - SOLICITATION OF MEANINGFUL INVOLVEMENT BY POTENTIAL USERS
  - FOLLOW-UP MEETINGS TO REFINE USER NEEDS
- GOALS ACCOMPLISHED
  - USER INTERACTION AND COMMUNICATION STIMULATED
  - USER DATA COLLECTED
  - ENDORSEMENT OF MISSION SCENARIOS
- PLAN PROVIDED SUPPORTIVE USER DATA FOR ESTABLISHING CREDIBLE LONG-TERM SPACE STATION REQUIREMENTS

USER CONTACT PLAN

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The Lockheed approach to develop users needs was to meet with the users on a personal basis or in small groups. This technique tended to favor a more relaxed meeting and seemed to result in a good "give and take" dialog. Though we have covered all mission categories extensively, we placed extra emphasis on the Commercial and National Security areas and, in accord with NASA desires we used NASA contacts for expanding our data base in the scientific field. Extensive contacts were also made with foreign companies and agencies.





## USER CONTACT PLAN

- SMALL GROUP APPROACH - DISCIPLINE ORIENTED
- FOLLOW-UP CONTACT CONCEPT
- EMPHASIZED NATIONAL SECURITY AND COMMERCIAL
- SCIENCE CONTACTS (PRIMARILY THROUGH NASA)
- APPLICATIONS (OVERLAPPED WITH COMMERCIAL AND SCIENCE)
- OPERATIONS/LOGISTICS SUPPORT INTEGRAL TO ALL CATEGORIES
- FOREIGN CONTACTS (EXPRESSED CONSIDERABLE INTEREST)
- INFORMATION FROM CONTACTS ENTERED INTO COMPUTERIZED DATABASE
- SEMINAR TO EDUCATE HIGH LEVEL COMMERCIAL INTERESTS



USER INTERACTION

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The first study task, Mission Requirements, consisted of three main subtasks - user contacts and meetings, defining user needs, and consolidating those needs into mission requirements.

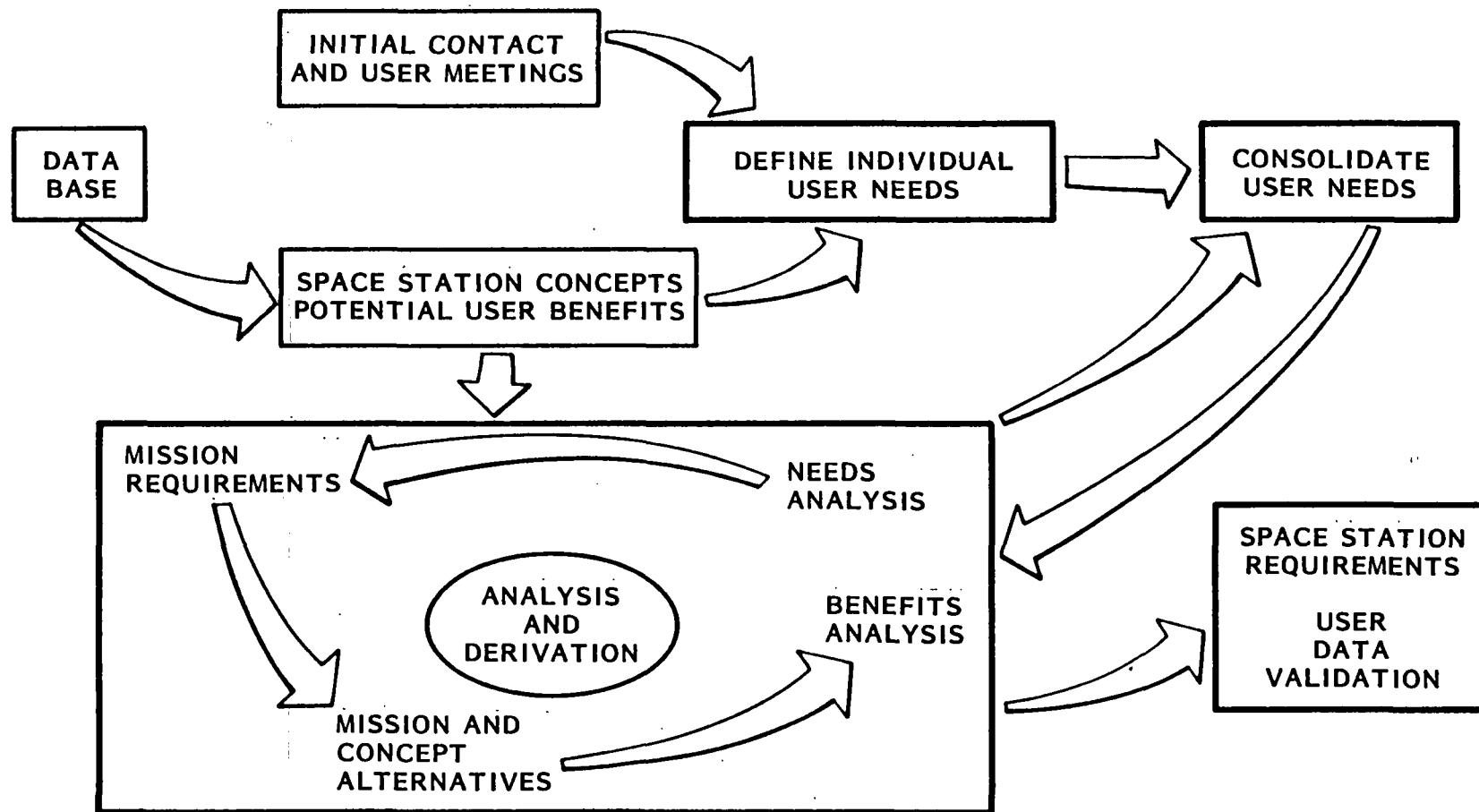
After reviewing the NASA data base for potential Space Station missions, initial contacts and meetings were held with potential station users or experimentors. Individual user needs were slower in developing than we desired, therefore, we decided to develop specific space station scenarios and concepts as a means of confirming and solidifying user needs. As these needs were defined, the third subtask of consolidating needs was accomplished and provided an input to the analysis and derivation effort. These analyses had an output consisting of architectural concepts and cost and benefit analyses. The output of this effort was in turn reviewed with users to validate the concepts and conclusions derived during the study.





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## USER INTERACTION



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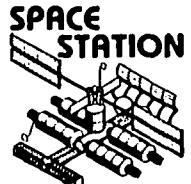
## REQUIREMENTS/SCENARIOS DEVELOPMENT PROCESS

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For each mission category, such as life sciences, commercial, etc., scenarios were selected and developed and gross needs were estimated. From these scenarios high level support characteristics were categorized for payload accomodations. After being finalized this data was used to define system requirements, system concepts, and architectural options for comparative trade-off and cost/benefits analyses.

The primary use of the scenarios initially was to have a means for the user to be able to visualize a mission or space station concept and thus for them to have a starting point for developing requirements. As the study developed, the scenarios became a useful means for grouping types or classes of missions which resulted in a smaller more manageable number of space station concepts.





PROGRAMS

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## REQUIREMENTS/SCENARIOS DEVELOPMENT PROCESS

### INPUTS

- USER CONTACTS
- DATA BASE

HELPED FORMULATE

### SCENARIOS

- MISSIONS
- ARCHITECTURAL CONCEPTS

WHICH DEFINED

### MISSION CHARACTERISTICS

- SYSTEM REQUIREMENTS
- COST/BENEFITS
- DATA SHEETS

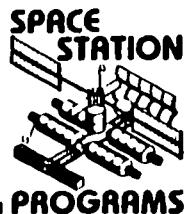
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REQUIREMENTS/SCENARIO SUMMARY

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An extensive list of people were contacted to further develop the mission requirements provided in NASA's identified data base. Based on initial information from these two sources, a number of scenarios were developed as a means of obtaining user concurrence. These scenarios were helpful in further refining user requirements in a number of cases. Data sheets summarizing mission characteristics, combined by scenario, were provided to LaRC for the NASA space station data base.





## REQUIREMENTS/SCENARIO SUMMARY

- OVER 320 INDIVIDUALS CONTACTED PERSONALLY, MANY OF THEM MULTIPLE VISITS
- DATA BASE (ARTS) HAS 245 IDENTIFIED MISSIONS / EXPERIMENTS
- 17 SCENARIOS DEVELOPED FROM VISITS AND DATA BASE
- MISSION CHARACTERISTICS WERE DEVELOPED FOR EACH SCENARIO

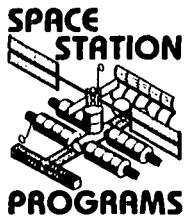
The Lockheed logo, which includes a stylized arrowhead pointing to the right followed by the word "Lockheed".

SUMMARY OF USER CONTACTS AND VISITS

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A breakdown of the 323 individuals visited, out of over 450 contacted, is shown by area - Science and Application, Commercial, National Security, and International. The number of people visited more than once is also shown.





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## SUMMARY OF USER CONTACTS AND VISITS

● SCIENCE AND APPLICATION	-	117 CONTACTS, 14 MULTIPLE VISITS
- LIFE SCIENCES		
- PHYSICAL SCIENCES		
- TECHNOLOGY		
● COMMERCIAL	-	98 CONTACTS, 13 MULTIPLE VISITS
- MEDICAL		
- MATERIAL PROCESSING		
● US NATIONAL SECURITY	-	68 CONTACTS, 22 MULTIPLE VISITS
● INTERNATIONAL	-	43 CONTACTS, 8 MULTIPLE VISITS
TOTAL CONTACTS	-	326, INCLUDING 57 CONTACTED MORE THAN ONCE



USER ALIGNMENT PLAN CONTACT LIST

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A sample of the contact list for the User Alignment Plan is shown in the adjacent chart. Over 450 people were contacted and 323 of them were actually visited. The particular computer program used to maintain our contact listing can be used to sort by agency visited, contactor, date of visit, area of the country, or general area of interest. This proved to be a valuable tool in coordinating trips, meetings and telephone contacts.





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## USER ALIGNMENT PLAN CONTACT LIST

ORIGINAL PAGE 10  
OF POOR QUALITY

REPORT # 24-NAK-83 SORTED BY ARTEMIS RECORD NUMBER				SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTUAL OPTIONS						PAGE 19	
UPDATE REF #####-OFFICE-#####	AGENCY/ COMPANY	USERNAME	PHONE	LOCATION/ CITY	REG CD MEMBER-1	MEMBER-2	MEMBER-3	CONTACT TEAM-#####	#####-VISITS-#####	SCHED	ACTUAL
438 DDS	USAF	COL E ROSS		PETERSON AFB KW M FORSBERG	P.SMITH	HUNTER				10-MAR-83	10-MAR-83
439 XPSS	USN	CAPT AE ROVE		PETERSON AFB KW M FORSBERG	P.SMITH	HUNTER				10-MAR-83	10-MAR-83
REPORT # 24-MAR-83 SORTED BY ARTEMIS RECORD NUMBER				SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTUAL OPTIONS						PAGE 10	
UPDATE REF #####-OFFICE-#####	AGENCY/ COMPANY	USERNAME	PHONE	LOCATION/ CITY	REG CD MEMBER-1	MEMBER-2	MEMBER-3	CONTACT TEAM-#####	#####-VISITS-#####	SCHED	ACTUAL
214	TEPLAC DR CH HD	317/494-6300 W. LAFAY IN		KW KP GRODZKA						10-MAR-83	10-MAR-83
215	NASA M. KREUGER	202/755-3970 HQTR		EA M STRAIGHT						17-MAR-83	17-MAR-83
REPORT # 24-MAR-83 SORTED BY ARTEMIS RECORD NUMBER				SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTUAL OPTIONS						PAGE 1	
UPDATE REF #####-OFFICE-#####	AGENCY/ COMPANY	USERNAME	PHONE	LOCATION/ CITY	REG CD MEMBER-1	MEMBER-2	MEMBER-3	CONTACT TEAM-#####	#####-VISITS-#####	SCHED	ACTUAL
1 SPACE SYS OUDRE	DOO CO FORSYTHE	202/697-8157 PENTAGON		EA M FORSBERG FORSBERG FORSBERG FORSBERG	STECMAN P. SMITH STECMAN P. SMITH	HUNTER 14-OCT-82 14-OCT-82 14-OCT-82 14-OCT-82		13-SEP-82 13-SEP-82 13-SEP-82 13-SEP-82	16-SEP-82 16-SEP-82 16-SEP-82 16-SEP-82	15-OCT-82	15-OCT-82
2 NSP (PMF 106)	USN DR. FM DIETRICH	202/692-2182 WASH DC		EA M FORSBERG FORSBERG	STECMAN P. SMITH	HUNTER 16-NOV-82 16-NOV-82		13-SEP-82 13-SEP-82 13-SEP-82 13-SEP-82	26-AUG-82	26-AUG-82	26-AUG-82
3 NSP (PMF 106)	USN	202/692-2182 WASH DC		EA M FORSBERG	STECMAN	HUNTER 16-NOV-82 16-NOV-82		13-SEP-82 13-SEP-82 13-SEP-82	26-AUG-82	26-AUG-82	26-AUG-82
4 NAV OCEANOGRAPHIC USN CDR D HONHART 202/254-4562 WASH DC										13-SEP-82 14-OCT-82 27-OCT-82	14-SEP-82 14-SEP-82
5 HQ USAF/INET	USAF LCOL J B GROSS	202/695-7193 PENTAGON		EA M FORSBERG FORSBERG FORSBERG	STECMAN P. SMITH	HUNTER 13-DEC-82 13-DEC-82		13-SEP-82 13-SEP-82 13-SEP-82 13-SEP-82 13-SEP-82	15-OCT-82 15-OCT-82 15-OCT-82 15-OCT-82 15-OCT-82	15-DEC-82	15-DEC-82

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## DEVELOPMENT OF PAYLOAD ACCOMMODATION MISSIONS FROM USER SURVEY

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The following list of "Scenarios" are representative of classes of missions NASA uses in their mission models. These tend to be more "function oriented" than mission oriented.

The earliest use date refers to a time when the users we contacted felt a space station with the functional capabilities they required would be beneficial. This date does not drive availability in our growth concept but is simply one input to the capability evolution. The scenarios are described as to functions and impact on operations in other areas of this report.

The scenarios were used in user contacts with the objective of obtaining solid endorsement of some of the scenarios for which requirements could then be defined. This technique, though it did not result in a large number of solidly endorsed missions, proved successful in establishing meaningful dialog with users and led to definition of a substantial number of mission requirements.





## DEVELOPMENT OF PAYLOAD ACCOMMODATION MISSIONS FROM USER SURVEY

<u>SOURCE</u>	<u>MISSION SCENARIO</u>	<u>EARLIEST USE</u>
USER SURVEY	LIFE SCIENCE HUMAN RESEARCH LAB	1990
● SCIENCES	LIFE SCIENCE NON-HUMAN RESEARCH LAB	1990
	CELESTIAL OBSERVATORY	1990
	SPACE ENVIRONMENT FACILITY	1990
● APPLICATIONS	EARTH OBSERVATION FACILITY	1990
	GLOBAL HABITABILITY OBSERVATION LABORATORY	1990
	METEORLOGICAL FACILITY	1990
	MATERIAL PROCESSING RESEARCH LAB	1990
● COMMERCIAL	MATERIAL PROCESSING FACILITIES	+ 5 YRS
	SPACE OBSERVATION DEVELOPMENT LABORATORY	1990
	OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB	1990
● U.S. NATIONAL SECURITY	ORBITING NATIONAL COMMAND POST - NASA IMPACT	1990
	- OPERATIONAL	1998
	SPACE OBJECTS IDENTIFICATION SYSTEM	1995
	ON ORBIT SATELLITE SERVICING-LEO (ITSS, SBR, GPS)	1993
● SPACE OPERATIONS	LARGE STRUCTURES ASSEMBLY (SBR)	1992
	ASTRONOMY PLATFORM SUPPORT	1990
	SPACE TELESCOPE MAINTENANCE	1990
	PROMPT SATELLITE REPLACEMENT	1993
	SHUTTLE CREW RESCUE VEHICLE	1990
	GEO SATELLITE RESUPPLY	1990

DATA BASE

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The data base LMSC used for the space station study consists of data for 245 space missions. The primary sources of specific user needs were NASA lists of planned missions. The NASA documents were used because they were a prioritized identification of primarily scientific missions for the next two decades.

The data base was used as an input for our initial contacts with potential users. A complete print-out of the data base has been included in Attachment 2, Volume I of the final report.

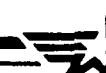
The list was pared down to 90 missions which have meaningful data appropriate to the space station. We did not try to embellish or augment the data as originally provided by the NASA reports, unless the user was specifically motivated to add information (which happened only in a few cases). While all the missing information could be added, and while requirements flow-down can generate very detailed subsystem information which will ultimately be needed for the space station design, we feel strongly that if the users cannot provide the information then it is outside the scope and intent of this study; such enhancement would give the data the unwarranted appearance of greater validity and would be in the long run counterproductive.





## DATA BASE

- 245 EXPERIMENTS, MISSIONS, SCENARIOS ENTERED IN DATA BASE
  - 4 MAJOR CATEGORIES
  - 9 SUB-CATEGORIES (FAMILIES)
- SUMMARY LISTING OF DATA BASE AND DESCRIPTION OF PROGRAM (ARTS) IS PRESENTED IN THE FINAL REPORT

 Lockheed

The Lockheed logo features a stylized arrowhead pointing upwards and to the right, followed by the word "Lockheed" in a bold, sans-serif font.

DATA BASE FORMAT

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A sample mission from the data base is shown in the adjacent chart. Characteristic user needs identified from this data base provided the basis for our initial mission scenarios and space station concepts.





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## DATA BASE FORMAT

REQID	SA28E0
SOURCE	SP82-MSFC-2583, 3-82
CONTACT/AUTHOR	R. ISE, MSFC
DERIVATION	SA1310
FAMILY	PS/GE/PH/I
MISSION/EXPERIMENT	IMAGING SPECTROMETRIC OBSERVATORY (ISO)
ALTITUDE	250 (KM)
INCLINATION	ANY
ORBIT	
MISSION DURATION	NO LIMIT
TECHNOLOGY DATE	
SIZE	1.10 X Ø.84 X 1.3Ø (M)
WEIGHT/MASS	ØØ245 (KG)
AVERAGE POWER	ØØ.19Ø (KW)
PEAK POWER	ØØ.215 (KW)
DATA (I/O RATES)	2000.Ø (KBPS)
DATA (STORAGE CAP)	
STABILITY	> 1 ARC MIN
POINTING ACC	> 1 ARC MIN
MANNING	
INTERFACES	RAU/HRM
SERVICE/MAINT	
LOGISTICS	
THERMAL/CNTRL	COND Ø.19 (KW) COLD PLATE
OPERAT ENVIRON	
CONSUMABLES	
TEXT	SA2880.TXT

The ISO instrument flying on SL-1 consists of an array of five spectrometers integrated as a pallet-mounted unit plus a rack-mounted control unit. The spectrometers provide 3-10 Å resolution over the wavelength range 300-12000 Å. Instrument is modular design so that gratings and detectors can be easily changed. Fewer than five modules can be flown if desired. Instrument could be mounted in IPS if desired.

ISO experiments measure the optical emissions from the Earth's atmosphere, the spacecraft induced atmosphere, artificially induced aurorae, and the interplanetary and interstellar media. ISO operates in a survey mode. Viewing opportunities/interests exist throughout each orbit. Typical viewing sequences last 20-30 min. SL-1 operations are planned on a two-shift basis, four personnel each shift. Nominal operation of the ISO experiment is accomplished by DEP software under the control of timelined commands.

Special Requirements: Physical alignment with horizon sensor desired within 2 degrees. Alignment knowledge desired within 1 arc min. ISO desires no illuminated object within 20 deg of FOV. Other requirements include sun >30 deg from FOV and moon >20 deg from FOV.

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## USER ALIGNMENT PLAN CONCLUSIONS

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The approach taken to define space station requirements was to utilize existing data where available, to acquire requirements through personal contacts with potential users. The existing data base provided adequate coverage of requirements in the science area, particularly, physical sciences. A substantial number of personal contacts were made in the life sciences and applications area to expand this data base. Definition of requirements was found to be very limited in the area of commercial applications and therefore a considerable number of personal contacts were initiated and two seminars were held under joint sponsorship of Lockheed and the Arthur D. Little Company. Both the contacts and seminars proved to be beneficial in developing commercial user interest but neither resulted in significant numbers of hard requirements.

Substantial emphasis was placed on U. S. National Security and strong interest has been developed in several areas as a result of our visits.

Tied in closely with the present non-existence of significant requirements was a general lack of knowledge about space. Most people not closely allied to the aerospace industry are not familiar with the environment they would be dealing with and cannot judge the advantages and benefits that are possible.

To develop a broad base for commercial users of space and a space station system, it is imperative for NASA to keep their plans highly visible to potential users as well as to help them become familiar with space characteristics.





## USER ALIGNMENT PLAN CONCLUSIONS

- USER ALIGNMENT PLAN SUCCESSFUL
  - RAISED POTENTIAL USER INTEREST
  - CREATED POTENTIAL SPACE BUSINESS OPPORTUNITIES
- USERS NOT READY FOR SPACE STATION
  - MANY POTENTIAL USERS NOT SUFFICIENTLY FAMILIAR WITH SPACE
  - USERS NEED MORE TIME TO DEVELOP THEIR REALISTIC NEEDS
  - MANY USERS DO NOT PLAN 5-7 YEARS DOWNSTREAM
  - POTENTIAL USERS WANT TO KNOW HOW AND WHAT SPACE CAN DO
- WHAT CAN BE DONE?
  - RECOMMEND CONTINUING FOLLOW-UP WITH USER ALIGNMENT PLAN
  - CREATE NASA "SPACE UTILIZATION GROUP" TO HELP POTENTIAL USERS BECOME FAMILIAR WITH SPACE OR PERFORM EXPERIMENTS USING THE STS
  - KEEP SPACE STATION PLANNING VISIBLE TO USERS

## COMMERCIAL STUDY FINDINGS

The proposed alignment plan was successfully executed and many promising contacts were made. The two seminars yielded 50 attendees and 26 requests for return visits. Presentations to trade groups yielded invitations to exhibit on a trade fair and tell people about space station. Substantial foreign interest was exhibited but with the many barriers it is hard to effectively use this energy in the present day atmosphere. Serious attention should be given to a foreign partnership rather than just cooperation and data exchange.

Discussions with prospective users turned up the fact that there is not enough information on specific facts of what can be done in space, what the costs are and what return can be expected. People in industry are in the business of making money, and want a much clearer view of the possibilities before they start investing in space ventures.

The commercial user alignment activity identified a number of users who would like to invest in commercial uses of space, but who do not have adequate data to make either technical or financial judgments. These data must be developed - at the research and development level - by NASA. As a direct result of this study, NASA now has a large, specific group of interested users; by directing research specifically into areas of interest to this group, and by keeping them closely advised of progress, NASA has a unique opportunity to bring successful research rapidly to the attention of interested and motivated commercial users who have expressed interest in developing suitable products on their own funds if the data indicate a reasonable possibility of positive financial return. Until this cycle is completed, no realistic estimate of commercial requirements for or benefits from a space station can be developed.

It is the governments' duty to create a proper environment for doing business in space.





## COMMERCIAL STUDY FINDINGS

- THERE IS INCREASING INTEREST IN SPACE STATION
- THERE IS WILLINGNESS TO HELP, BUT USERS EXPRESS CONCERN ABOUT BUDGET (AFRAID TO COMMIT)  
CONCERN ABOUT NASA OBJECTIVITY  
CONCERN ABOUT NEED FOR MAN IN SPACE BEYOND SHUTTLE  
(MIXED REACTION)  
CONCERN ABOUT BEING BEHIND IN SPACE ACTIVITY
- USER INTERACTION IS VITAL TO THE PROGRAM
- NO NEW SPACE STATION FUNCTIONS HAVE BEEN IDENTIFIED - BUT MISSIONS MUST BE RESTATED IN TERMS OF USER NEEDS
- SUPPORT FOR MISSION SCENARIOS NOW BEING RECEIVED (PARTICULARLY FROM DOD)

## CONCLUSIONS

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The consensus of the people contacted was that the space station will definitely offer large economic benefits when build and available for all to use.

The categories of potential users contacted were science and applications, commercial, US national security, and operations. The commercial area will eventually result in appreciable benefits however, presently the pay-offs are unknown. A marked need for further effort to educate and show experimental results to stimulate commercial ventures in space is crucial. Pay-off possibilities in the categories of space operations and national security are readily shown.

National prestige is of course a strong facet of a program as visual as space station. The political advantage internationally is difficult to analyze but it is certainly very large.





## CONCLUSIONS

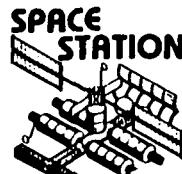
- SPACE STATION OFFERS ECONOMIC BENEFITS
  - COMMERCIAL PAYOFFS UNKNOWN
  - MUST EDUCATE, EXPERIMENT & ESTABLISH WORKABLE BUSINESS ENVIRONMENT
  - SATELLITE SERVICING PAYOFF LARGE
  - DESIGN FOR MAINTAINABILITY OTV'S ESSENTIAL
- SPACE STATION OFFERS RESCUE CAPABILITY
  - STATION-BASED RESCUE VEHICLE PROVIDES ALTERNATIVE TO BACKUP SHUTTLE LAUNCH FOR RESCUE OF ORBITER CREW
- SPACE STATION OFFERS NATIONAL SECURITY
  - RESEARCH & DEVELOPMENT
  - OPERATIONAL CAPABILITY
- SPACE STATION OFFERS NATIONAL PRESTIGE
  - PERMANENT MANNED PRESENCE IN SPACE
  - LEADERSHIP IN SPACE TECHNOLOGY
  - PURSUIT OF SCIENTIFIC FRONTIERS

LOCKHEED ASSESSMENT OF SPACE STATION NEED

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A space station should be initiated now for initial operations in the early 1990's. By the latter half of the 90's launch costs can be expected to be reasonable, and manned space operations will be routine, efficient, and essential to the well being of the United States.



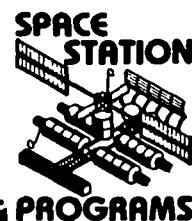


## LOCKHEED ASSESSMENT OF SPACE STATION NEED

THE CAPABILITY FOR MANNED SPACE OPERATIONS IS ESSENTIAL TO THE  
WELL BEING OF THE UNITED STATES

A SPACE STATION PROGRAM SHOULD BE INITIATED NOW

 Lockheed



## **TASK 1—MISSION REQUIREMENTS**

- 1.1 USER ALIGNMENT PLAN**
- 1.2 SCIENCE AND APPLICATIONS**
  - PHYSICAL SCIENCES
  - LIFE SCIENCES
- 1.3 COMMERCIAL**
- 1.4 U.S. NATIONAL SECURITY**
- 1.5 SPACE OPERATIONS**
- 1.6 REQUIREMENTS FROM USER NEEDS**
- 1.7 FOREIGN CONTACTS**

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# PHYSICAL SCIENCES

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PHYSICAL SCIENCES - TOPICS CONSIDERED

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Physical science community user needs are considered from several different aspects. The benefits of a manned space station are first summarized, as well as concerns that have been raised by scientists. This is followed by an identification of general uses, an assessment of specific user needs, and conclusions.



## PHYSICAL SCIENCES-TOPICS CONSIDERED

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- BENEFITS OF A SPACE STATION
- SCIENTISTS CONCERNs
- GENERAL USES OF A SPACE STATION
- SPECIFIC USER NEEDS
- CONCLUSIONS

BENEFITS OF A SPACE STATION

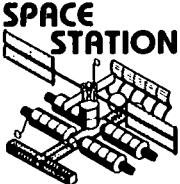
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In what ways will the physical science community benefit from a manned space station? The benefits can be separated into those that derive from the space station capabilities and those that derive from having a manned system.

Obvious benefits of a space station are the relaxation of the size, mass and power constraints of the STS/Spacelab system. In addition, scientists will benefit from the opportunity of having several experiments being performed simultaneously (e.g. observations of solar activity and atmospheric response). Finally, a space station provides continuous measurements over a long time period, a significantly increased benefit over the two-week Shuttle sortie missions at infrequent intervals. This is especially important for scientific measurements of targets-of-opportunity, such as solar flare studies.

What are the advantages of having a manned system? A significant benefit is expected because a manned facility enables the deployment of complex systems. Some scientific facilities are so complex that the operation in an automated unmanned mode is extremely difficult and costly. Examples of such systems are: incoherent-scatter radars for ionospheric studies; LIDAR (laser radar) systems for remote-sensing of atmospheric properties; and subsatellite systems deployed on long tethers. Another benefit of a manned system is that it allows on-site decisions to be made regarding initiation of target-of-opportunity measurements, and real-time monitoring and control of data quality. Finally, the capability of on-orbit maintenance and repair should increase the lifetime of scientific systems and allow systems to be simpler with fewer redundancies.





## BENEFITS OF A SPACE STATION

### • SPACE STATION CAPABILITIES

- SIZE
- MASS
- POWER
- MULTIPLICITY OF EXPERIMENTS
- LONGEVITY
- CONTINUITY

### • MANNED CAPABILITIES

- OPERATION OF COMPLEX SYSTEMS (E.G., LIDAR, INCOHERENT-SCATTER RADAR, TETHERED SATELLITES)
- ON-SITE DECISION-MAKING (EXPERIMENT INITIATION, SELECTION OF OPERATING MODES, DATA QUALITY CONTROL)
- SYSTEM MAINTENANCE AND REPAIR

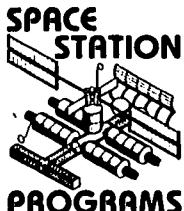
CONCERNS EXPRESSED BY SCIENTISTS

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Despite the many benefits of a space station, concerns have been expressed by scientists. The chart lists the major concerns, as well as ways to alleviate them. In general, remedial action consists of program management by NASA Headquarters to ensure that science user needs are met in space station design and implementation.

These scientist-concerns are discussed in more detail in "Space Science Research in the United States," Office of Technology Assessment Technical Memorandum, September 1982, pp. 12-16.





## CONCERNS EXPRESSED BY SCIENTISTS

<u>CONCERN</u>	<u>REMEDY</u>
STATION MAY CONSTRAIN SCIENCE BECAUSE OF ORBITAL LOCATION	RETAIN CAPABILITY FOR ACCESS TO OTHER ORBITS
EXPERIMENT REQUIREMENTS FOR STABILITY, ETC. INCOMPATIBLE WITH A MANNED STATION	INCLUDE SCIENCE REQUIREMENTS IN STATION DESIGN; USE OF SUBSATELLITES
SKEPTICISM REGARDING PROMISED CAPABILITIES BEING ACTUALLY ACHIEVED	PROGRAM MANAGEMENT TO ENSURE ACHIEVEMENT OF CAPABILITIES
IMPACT ON NASA SCIENCE BUDGET	MAINTAIN NASA SCIENCE PROGRAMS
PREEMPTION BY MILITARY	PROGRAM MANAGEMENT, MULTIPLE STATIONS

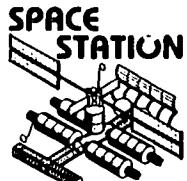
## PHYSICAL SCIENCE USES OF SPACE STATION (1)

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The uses of a space station for the physical science community can be divided into several categories. These include: observatory measurements, where observations are made of objects at a distance; experimental laboratory research, which takes advantage of the unique environment in earth orbit; and operations in support of research studies.

Specific examples of these categories are listed on the next chart.





PROGRAMS

## PHYSICAL SCIENCE USES OF A SPACE STATION (1)

- OBSERVATORY MEASUREMENTS
- EXPERIMENTAL RESEARCH LABORATORY
- OPERATIONS CENTER

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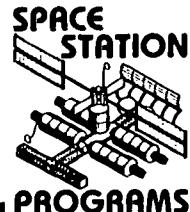
## PHYSICAL SCIENCE USES OF A SPACE STATION (2)

Observatory measurements include most of the research programs that have dominated space physics research during the past two decades. These include measurements of phenomena ranging from as near as the earth's surface to as distant as astrophysical sources.

As an operations center, the space station can enable repair and maintenance of free-flyers as well as instrumentation on the space station. Satellites for planetary exploration can be configured and checked out before being sent on their planetary journey. In addition, extraterrestrial samples can be examined in a laboratory/quarantine facility on the space station. An important use will be construction of large structures too big to be conveniently assembled during a shuttle flight.

The final category of use is an experimental research facility aboard the space station that can take advantage of the low-gravity and high-vacuum that is readily available.





## PHYSICAL SCIENCE USES OF A SPACE STATION (2)

- OBSERVATORY MEASUREMENTS
  - EARTH OBSERVATIONS
  - ATMOSPHERIC PHYSICS
  - IONOSPHERIC PHYSICS
  - MAGNETOSPHERIC PHYSICS
  - SOLAR PHYSICS
  - PLANETARY STUDIES
  - ASTROPHYSICS
- OPERATIONS CENTER
  - FREE FLYERS
  - CONSTRUCTION BASE FOR LARGE STRUCTURES
  - PLANETARY EXPLORATION
- EXPERIMENTAL FACILITY
  - ACTIVE SPACE EXPERIMENTS
    - o SPACE PLASMAS
    - o CHEMICAL RELEASES
  - LABORATORY MEASUREMENT/EXPERIMENTS
    - o MICROGRAVITY EXPERIMENTS
    - o VACUUM EXPERIMENTS
    - o MATERIALS SCIENCES LABORATORY
    - o CLOUD PHYSICS LABORATORY
    - o CHEMICAL KINETICS LABORATORY
    - o LOW-GRAVITY PLANETOLOGY
    - o LABORATORY

IDENTIFICATION OF USER NEEDS

---

The primary sources of specific user needs were NASA lists of planned missions. This data base was used because it is a prioritized identification of scientific missions for the next two decades. The only serious limitation to the candidate mission list is that it is now constrained by Shuttle/Spacelab capabilities. Therefore, the candidate mission list was supplemented with advanced concepts that have requirements that exceed Space Shuttle capability. A direct solicitation to the space science community for candidate missions was judged to be inefficient because it ignores the many studies performed during the past two decades. However, input from scientists at Lockheed and elsewhere was used for identification of user needs and space station architecture.

The user requirements for over 200 science and applications missions were entered into the ARTS data system at Lockheed. Characteristic user needs identified from this data base are described in the following charts.

In addition to the large ARTS data base, several specific scenarios were developed for identification of typical user needs.





## IDENTIFICATION OF USER NEEDS

- SPECIFIC USER NEEDS OBTAINED PRIMARILY FROM NASA LISTS OF PLANNED AND APPROVED MISSIONS. THESE WERE AUGMENTED BY SUGGESTIONS FROM INDIVIDUAL SCIENTISTS.
- ARTS DATA BASE INDICATING USER REQUIREMENTS FOR OVER 200 SCIENCE AND APPLICATIONS MISSIONS.
- SEVERAL SCIENCE AND APPLICATIONS MISSION SCENARIOS DEVISED AS TYPICAL SPACE STATION USES.



## USER NEEDS EXTRACTED FROM ARTS DATA BASE (1)

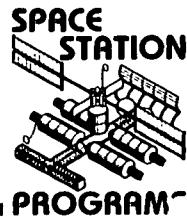
## TOTAL MASS

The ARTS data base consists of 245 space missions taken primarily from NASA documents (e.g. OAST/NASA Space Systems Technology Model, NASW-2937, NASA Headquarters, September 1981; Science and Applications Space Platform: Payload accomodations study, SP82-MSFC-2583, NASA/Marshall Space Flight Center, March, 1982).

In the ARTS data base missions were identified that are relevant to physical sciences uses of a manned space station. Excluded were life science missions and engineering missions, as well as missions not defined in sufficient detail so as to contain a specification of key requirements.

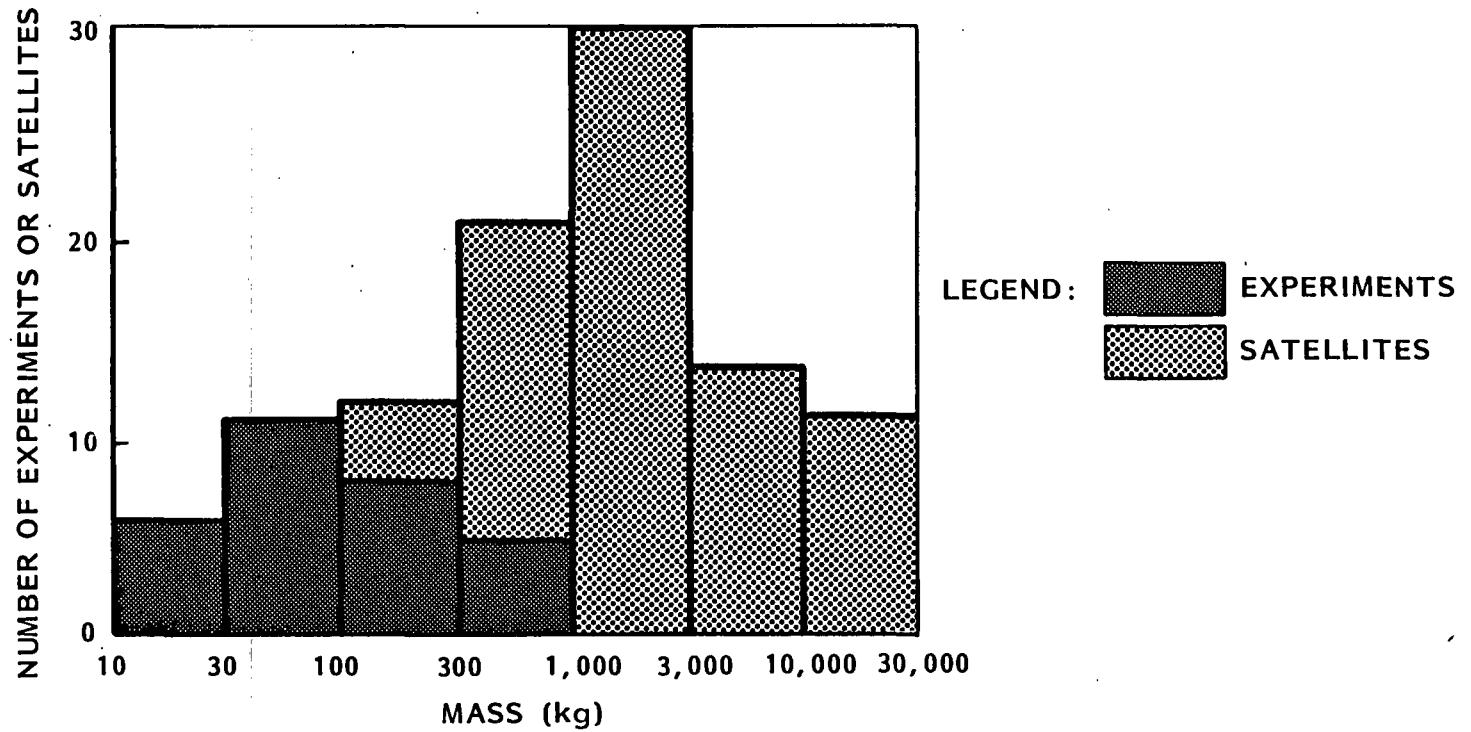
The distribution of total mass for the physical science missions in the ARTS data base is shown in this chart. The uses have been separated into experiments (which are generally single instruments) and satellites (which are systems of several instruments). The median mass was 824 kg. The heaviest system in the ARTS data base was the Very Large Space Telescope at 22,850 kg.





## USER NEEDS EXTRACTED FROM ARTS DATA BASE (1)

TOTAL MASS



## USER NEEDS EXTRACTED FROM ARTS DATA BASE (2)

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AVERAGE POWER CONSUMPTION

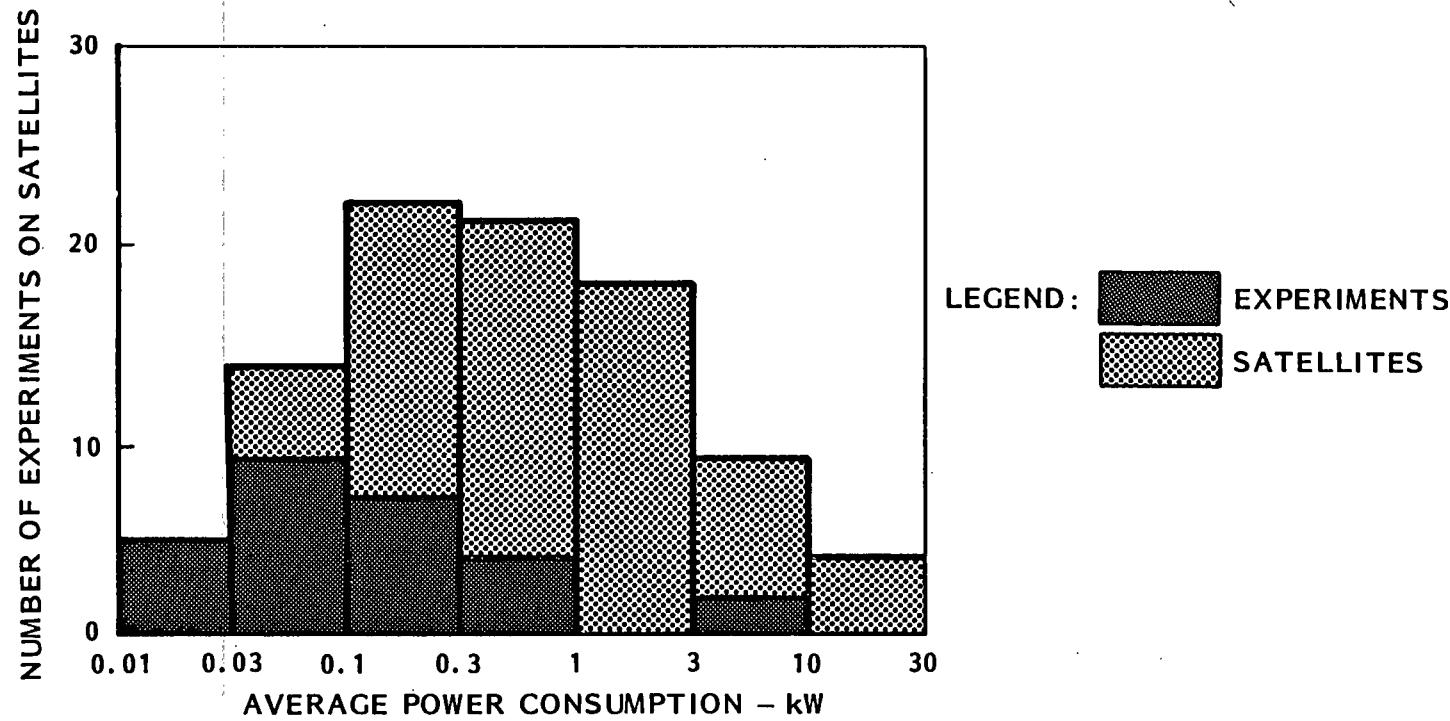
The distribution of average power consumption for science user needs in the ARTS data base is shown in the chart. The median power consumption was 420 W. Three systems had the largest power consumption of 25 kW: the Infrared Interferometer, the Coherent Optical System of Modular Imaging Collectors (COSMIC), and the 100-meter Thinned Aperture Telescope.





## USER NEEDS EXTRACTED FROM ARTS DATA BASE (2)

AVERAGE POWER CONSUMPTION



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## SPACE STATION SCENARIOS

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To identify typical user needs, several specific scenarios were developed as representative missions for physical science and applications. For each of these scenarios a system specification was made that could be used in the costing and time-phasing tasks of this study.

Each of the individual scenarios is summarized in an appendix of this report





## SPACE STATION SCENARIOS

SPACE STATION SCENARIOS FOR TYPICAL PHYSICAL SCIENCE AND APPLICATIONS USER NEEDS

- GLOBAL HABITABILITY OBSERVATORY
- CELESTIAL OBSERVATORY
- SPACE ENVIRONMENT FACILITY
- EARTH OBSERVATION FACILITY
- MATERIAL PROCESSING RESEARCH LABORATORY
- METEOROLOGICAL FACILITY



ADVANCED SCIENCE SYSTEMS

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An important shortcoming of the NASA lists of future programs is that they emphasize missions that are compatible with STS/Spacelab capabilities. Many advanced science missions (sometimes referred to by NASA as "horizon missions") are not now planned because they have requirements that exceed present capabilities. It is these missions for which a space station may be a solution.

These advanced systems have either large dimensions making them unsuitable for deployment by a shuttle mission, or high power in excess of the STS capability, or great complexity so as to require manned operation. Examples of systems that have antennas too large for deployment in a single shuttle mission are: (1) the 30-M Large Deployable Reflector (LDR) for infrared and sub-millimeter astrophysical observations; (2) the Orbiting Very Long Baseline Interferometer (OVLBI) for radio astronomy, and (3) the Search for Extraterrestrial Intelligence (SETI) program.





## ADVANCED SCIENCE SYSTEMS

- ADVANCED SCIENCE SYSTEMS THAT MAY REQUIRE SPACE STATION ARE THOSE THAT HAVE LARGE DIMENSIONS, GREAT COMPLEXITY OR HIGH POWER CONSUMPTION
- SPECIFIC EXAMPLES ARE:
  - LARGE-ANTENNA SYSTEMS (LDR, OVLBI, SETI)
  - LASER RADAR FACILITY
  - INCOHERENT-SCATTER RADAR FACILITY
  - GRAVITY-WAVE INTERFEROMETER



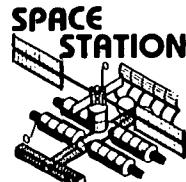
## EXAMPLE OF ADVANCED CONCEPT (1)

## GRAVITATIONAL - WAVE INTERFEROMETER

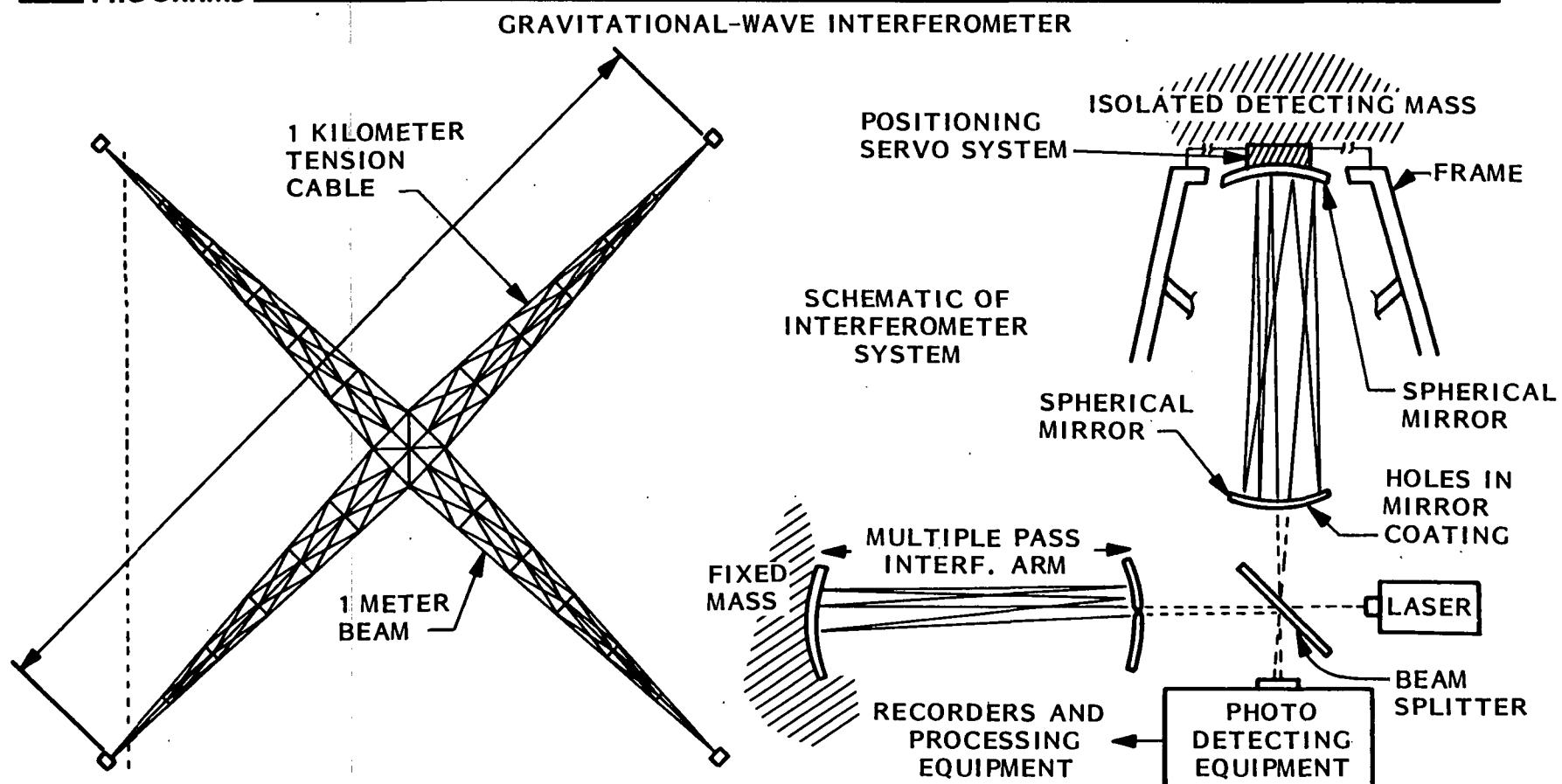
An example of an advanced concept that might require the space station capability is a gravity-wave interferometer. It is a large cross-shaped structure consisting of orthogonal beams, each a kilometer or more in length. One-ton masses are mounted at the four ends of the beams. A laser interferometer system is used to measure the small relative displacement of these masses that would be the signature of the passage of gravity waves. Although it may be feasible to construct and deploy such a system with Space Shuttle alone, the assembly and operation strain the Space Shuttle capability. Thus, this advanced concept may be a system that is made feasible by development of a manned space station.

The gravity-wave interferometer is described in more detail in "Gravitational Radiation Searches and Gravitational Wave Astronomy," Astrophysics Program Project Concepts, NASA Headquarters, October, 1980, pp. 21-24.





## EXAMPLE OF ADVANCED CONCEPT (1)



(FROM GRAVITATIONAL RADIATION SEARCHES AND GRAVITATIONAL WAVE ASTRONOMY, ASTROPHYSICS PROGRAM PROJECT CONCEPTS, NASA HEADQUARTERS, OCTOBER, 1980)

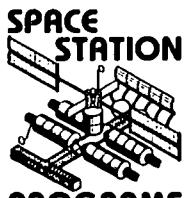
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## EXAMPLE OF ADVANCED CONCEPT (2)

## INCOHERENT SCATTER RADAR FACILITY

An incoherent-scatter radar system is another example of a science system that is feasible only on a space station. Incoherent-scatter radars can remotely measure all of the key physical parameters of the ionosphere and upper atmosphere. However, to operate effectively they require a large antenna, high power, and a complex data processing system. For these reasons, an incoherent-scatter radar facility on the Space Shuttle has been judged to be technically feasible, but cumbersome and impractical to implement (M. Baron, R. Tsunoda, J. Petriceks, and H. Kunnes, "Feasibility of an Incoherent-scatter Radar Aboard the Space Shuttle," Stanford Research Institute Report, March 1976; J. Ball, G. Fulks, T. Old, and W. Wortman, "Techniques for Remote Sensing of Ionospheric Electron Density from a Spacecraft," Mission Research Corporation Report, August 1981).

To be effective an incoherent-scatter radar typically requires a peak power-aperture product of about  $10^8$  watts-m<sup>2</sup>. For a peak pulse power of 10kW, an antenna is needed that is approximately 600 ft in diameter. Such a large antenna is probably not practical for an STS sortie mission. However, such an antenna could be deployed as part of a space station; or if large power systems are available, a smaller antenna could be used.



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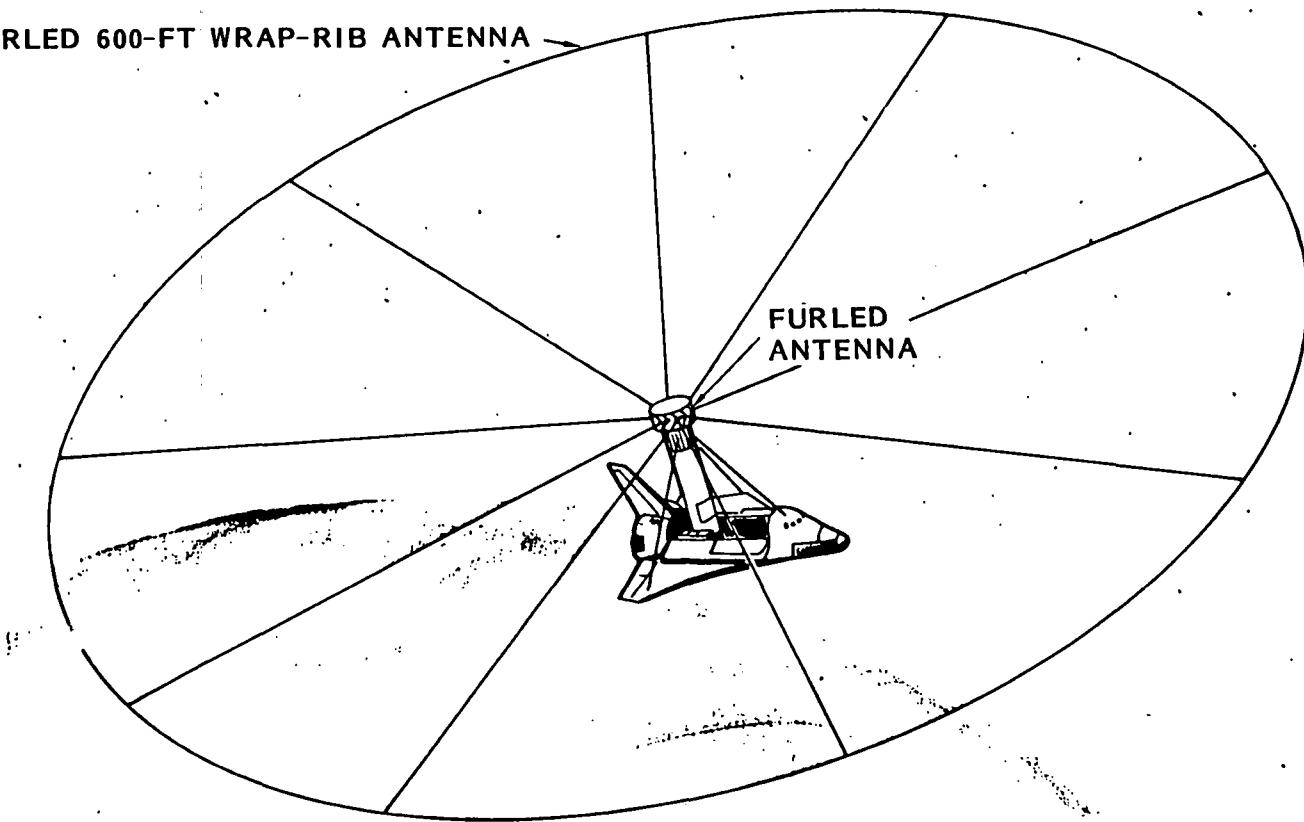
## EXAMPLE OF ADVANCED CONCEPT (2)

INCOHERENT-SCATTER RADAR FACILITY

UNFURLED 600-FT WRAP-RIB ANTENNA

FURLED  
ANTENNA

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ARTIST'S DRAWING OF 600-FT UNFURLED ANTENNA AND SPACE SHUTTLE

 Lockheed

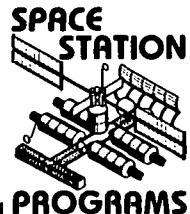
CONCLUSIONS

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Our assessment of user needs for physical sciences and applications resulted in several general conclusions:

1. Significant benefits can result from use of a space station by scientists. The primary benefits result from: The continuous operations over long time periods; the large structures and high power that will be available; and the manned operation, maintenance and repair of complex systems.
2. Most planned science missions are possible with a space station. Mission requirements identified with the ARTS data base were generally compatible with reasonable space station capabilities and do not seriously constrain space station architecture. The major exceptions are missions with unique orbital requirements (e.g., TOPEX).
3. The primary scientific benefit of a space station is that it will enable advanced science missions with requirements that now exceed STS capabilities. These missions have large dimensions, great complexity or high power consumption.





## CONCLUSIONS

- A MANNED SPACE STATION CAN BE OF SIGNIFICANT BENEFIT TO THE SCIENTIFIC COMMUNITY
- MANY PLANNED AND APPROVED SCIENCE MISSIONS ARE COMPATIBLE WITH SPACE STATION
- SPACE STATION WILL ALLOW DEVELOPMENT OF SCIENTIFIC SYSTEMS THAT ARE NOW CONSTRAINED BY STS CAPABILITIES





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# LIFE SCIENCES

 Lockheed

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1.2-31

## REASONS FOR RESEARCH IN SPACE

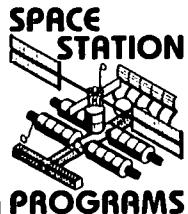
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Over the years the goals of the Space Life Sciences Program have been stated in various NASA documents. Among these are:

- Future Directions for the Life Sciences in NASA
- Life Sciences Division "Ten-Year Plan," July 1982
- Announcement of Opportunity OSS-1-78 Life Sciences Investigations on Space Shuttle/Spacelab Missions
- Space Sciences and Applications Notice, October 1982
- NASA Program Plans
- Annual NASA Budget Request Documents

The chart opposite is an LMSC composite of these goals statements.





## REASONS FOR RESEARCH IN SPACE

- TO UNDERSTAND AND MITIGATE THE EFFECTS OF THE SPACE ENVIRONMENT ON HUMANS SO THAT A VARIED SEGMENT OF THE POPULATION CAN PARTICIPATE DIRECTLY IN SPACE FLIGHT
- TO DEVELOP THE FOUNDATION FOR THE EXTENDED PRESENCE OF, AND EXTENDED OPERATION BY, HUMANS IN SPACE
- TO INCREASE MANKIND'S UNDERSTANDING OF THE EFFECTS OF THE UNIQUE SPACE ENVIRONMENT ON BIOLOGICAL PROCESSES
- TO USE THE SPACE ENVIRONMENT TO BETTER UNDERSTAND LIFE PROCESSES ON EARTH
- TO UNDERSTAND THE ORIGIN, EVOLUTION, NATURE, AND DISTRIBUTION OF COMPLEX LIFE IN THE UNIVERSE, AND TO UNDERSTAND ITS INTERACTION WITH THE ENVIRONMENT



WHY RESEARCH ON A SPACE STATION

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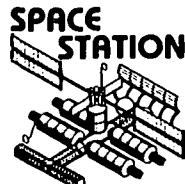
Most Life Sciences research areas require time periods greater than can be provided by Shuttle so that new physiological norms after exposure to zero gravity can be reached. The vestibular system appears to be the only exception, allowing end points to be reached during a Shuttle mission duration.

Current NASA planning calls for approximately three dedicated Life Sciences missions between now and 1991 when a space station would become operational. This results in only 20 to 30 total days on-orbit, which is small in comparison to the large investment. The NASA Life Sciences organization is spending approximately \$20M per year, exclusive of launch costs, for a 10 to 15 year period to support this effort.

A space station will provide far more continuous time on orbit and therefore has the potential to be more cost effective than Shuttle in terms of the amount of science gained per day on orbit and per dollar invested in facilities and equipment. The longer stay times also will result in higher quality science due to increased experimenter interaction.

Before man can proceed to the next step in space, which could be a colony or interplanetary exploration, Life Sciences research on a space station is required to qualify man for these endeavors and to develop any required countermeasures to the effects of prolonged exposure to zero gravity.





## WHY RESEARCH ON A SPACE STATION

- MOST LIFE SCIENCES RESEARCH REQUIRES LONGER THAN 7-10 DAYS
- PLANNED DEDICATED SHUTTLE/SPACELAB TIME BETWEEN NOW AND 1990 IS ONLY 20 TO 30 DAYS TOTAL ON ORBIT
- SPACE STATION PROVIDES CONTINUOUS TIME IN ORBIT
- SPACE STATION IS MORE COST EFFECTIVE
- LIFE SCIENCES RESEARCH ON SPACE STATION IS REQUIRED TO ENABLE MAN TO PROGRESS TO NEXT STEP

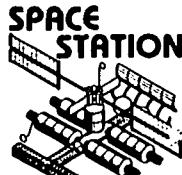


SPACE STATION USER SURVEY CONTACT LIST

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The initial task was to conduct a user survey. The adjacent chart shows contacts made in the life sciences area. The contacts were made by T.M. Olcott, LMSC Biotechnology Manager, C.E. Rudiger, LMSC Life Sciences Research Facility Program Manager, and/or Dr. L.O. Greene, Jr., LMSC Biotechnology Staff Scientist. Detailed trip reports covering what was learned during these interviews were prepared and have been submitted directly to Dr. Bill Bishop, Deputy Director, Life Sciences Division, NASA Headquarters.



**PROGRAMS****SPACE STATION USER SURVEY CONTACT LIST**NASA HEADQUARTERS

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GENE PETERSEN            MIKE SINGER  
GREG NELSON            CHERYL BERGSTROM  
TAK HOSHIZAKI

EXPERIMENT REQUIREMENTS

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In order to identify life sciences user requirements, candidate experiments to be performed on a space station were defined. These candidate experiments are only examples used to extract principles of procedures, equipment, and requirements to ensure that the architecture of the space station will be compatible with the experiment requirements. The list of candidate experiments was developed by using the experiments defined by NASA Headquarters in "Life Sciences Considerations for Space Station" as a starting point and adding to the list.

This was done by interviewing personnel within NASA, the Air Force, universities, research organizations, advisory committees, and other members of the scientific community. During the course of the interviews, the NASA list of experiments was reviewed and ideas for other pertinent experiments solicited. The experiment lists then were analyzed to establish characteristics that would impact architecture. These first included general characteristics such as orbit inclination, altitude, and pointing requirements. The experiments were then categorized by discipline category. The species and number of specimens required were established for nonhuman experiments. Priorities were established for the experiments. Crew involvement was assessed and data requirements were estimated. Experiment-unique hardware also was identified.

The analysis included identification of common life sciences laboratory equipment required to support all of the candidate experiments. These common items were identified and cross-referenced against the experiment lists. Development status of these common equipment items has been defined along with weight, volume, and power estimates. Items of equipment that can be shared between the human and nonhuman research laboratory have been identified.





## EXPERIMENT REQUIREMENTS

- EXPERIMENTS IDENTIFIED BY NASA
- EXPERIMENTS IDENTIFIED BY LOCKHEED SURVEY
- REQUIREMENTS
  - GENERAL PARAMETERS
  - DISCIPLINE CATEGORY
  - SPECIES AND NUMBER
  - PRIORITY
  - CREW INVOLVEMENT
  - DATA REQUIREMENTS
  - EXPERIMENT UNIQUE HARDWARE (WEIGHT, VOLUME, POWER)
- COMMON FACILITY REQUIREMENTS
  - EXPERIMENTS CROSS REFERENCED
  - DEVELOPMENT STATUS
  - CONFIGURATION

NONHUMAN EXPERIMENTS MATRIX

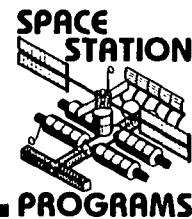
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Candidate experiments were listed for the nonhuman life sciences laboratory. The list includes the 17 experiments identified by NASA as well as eight experiments defined during Lockheed's user survey. The experiments are categorized as animal or plant physiology, cell development, or bioengineering. Species identification includes the primary species of interest as well as alternates where appropriate to enhance animal sharing. Those experiments whose specimens cannot be shared are noted. A determination has been made as to whether the experiment is open-ended or proceeds for a discrete time period.

An important consideration is the degree of manned intervention. The experiments have been segregated into three categories: (1) those requiring no manned intervention, which are candidates for platforms or early space stations where life scientists will not be part of the crew, (2) those requiring periodic intervention, which are candidates for intermediate stations with periodic visits of life sciences specialists, and (3) those requiring continuous intervention, which are candidates for more advanced stations that would have life scientists onboard at all times. The individual experiments were prioritized in terms of whether they: (1) solve known space biomedical problems, (2) solve short-term crew efficiency problems, (3) contribute to the development of advanced life support or health maintenance systems, (4) lead to a better understanding of biomedical problems on earth, (5) have a potential for non-NASA hardware spin-off, and (6) improve our understanding of the origin and distribution of life.

Data requirements and specialized experiment-unique hardware requirements have been determined for the candidate experiments.





# NONHUMAN EXPERIMENTS MATRIX

GENERAL PARAMETERS: Orbit; altitude - Below Radiation Belt; Inclination - Nonpolar  
Synchronization - None; Pointing and View direction - N/A; Environment - Shirtsleeve

Experiments	Discipline	Species (No. Required)												Duration	Degree of Required Human Intervention	Priority			Data Requirements
		RAT	MOUSE	SQUIRREL MONKEY	Rhesus MONKEY	FROG	CAT	BIRD	FISH	FROG EGGS	MOUSE EMBRYO	PLANTS	MICROBE CULTURES	CHICKEN EGGS	INSECTS	Long as Possible	Discrete	NONE	
1. CALCIUM HEMATOISIS	X			42 ALT											X				
2. MUSCLE FUNCTION	X			42 ALT											X				
3. FLUIDS/ELECTROLYTES	X			6 ALT											X				
4. METABOLISM	X			12 ALT											X				
5. VESTIBULAR PHYSIOLOGY	X			24 ALT											X				
6. VESTIBULAR MECHANISM	X			8 ALT	4 <sup>*</sup>	4	8	4	8	8					X				
7. ANIMAL REPRODUCTION	X	X		120 <sup>*</sup>	ALT	ALT	ALT	ALT	ALT	ALT					X				
8. RADIATION BIOLOGY (180 DAYS)	X			100											X				
9. RADIATION BIOLOGY (2 YEARS)	X			120											X				
10. CARDIOVASCULAR	X			4															
11. ANIMAL DEVELOPMENT (INFANT)	X	X		140											X				
12. ANIMAL DEVELOPMENT (EGGS)	X	X		20											X				
13. PLANT DEVELOPMENT	X	X													X				
14. PLANT PHYSIOLOGY	X	X													X				
15. CELSS (Seedlings)	X	X													X				
16. CELSS (Plants)	X	X													X				
17. CELSS (Cells)	X	X													X				
OTHER EXPERIMENTS																			
18. BODY MASS LOSS	X					4									X	X			
19. BIORHYTHMS	X				8	4	2	ALT							X			X	X
20. BEHAVIOR PERFORMANCE	X					4	2	ALT							X	X	X	X	X
21. CELLULAR & TISSUE REPRODUCTION & GROWTH	X					4 ALT		8 ALT							X	X			
22. IMMUNOLOGY HEMATOLOGY	X					4 <sup>*</sup>					X			None	X				
23. NEUROPHYSIOLOGY	X					4 <sup>*</sup>	2 <sup>*</sup>	2 <sup>*</sup>	4 <sup>*</sup>	4 <sup>*</sup>					X	X	X	X	X
24. ACCEL. IMPACT PHYSIO.	X	X				4 <sup>*</sup>	ALT	ALT	ALT	ALT					X	X			None
25. PLANT GEOTROPISM	X														X				None

\*Specimens that cannot be shared.

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COMMON SUPPORT HARDWARE  
(NONHUMAN) (1)

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A review of the candidate nonhuman experiments has resulted in the definition of common laboratory support hardware. These are items of equipment that will be used by more than one experiment. If similar items are under development by NASA, the ARC or JSC number also is listed. Equipment items have been cross-referenced against the experiments.

The development status of the equipment items is defined. Where the piece of equipment is being developed for Spacelab, the status of this equipment is defined. Many of the Spacelab items would require extensive modification before they could be used on a space station. A significant example of this is the Research Animal Holding Facility (RAHF) currently designed to support specimens for up to 14 days. Examples of modifications required to make it compatible with a space station with a 90-day resupply period are shown later.

Estimates of weight, volume, and power are presented for the common life sciences laboratory support hardware. These estimates are based on hardware being developed for Spacelab. The last column indicates items of equipment that can be shared by both the human and nonhuman laboratory.





## COMMON SUPPORT HARDWARE (NONHUMAN) (1)

HARDWARE REQUIREMENTS	REQUIRED BY EXPERIMENT NUMBER	DEVELOPMENT STATUS	WEIGHT (kg)	VOLUME (cu m)	POWER (W)	HUMAN USE ALSO
ANIMAL HLDG FAC (RODENT) (A005-1)	1-9, 11, 12, 21, 23, 24	FABRICATION	280	1	320	
ANIMAL HLDG FAC (SML PRI) (A005-2)	1-9, 11, 12, 19, 20, 22-24	FABRICATION	240	1	320	
ANIMAL HLDG FAC (LARGE PRIMATE)	10, 19, 20, 22, 23	CONCEPTUAL	200	2	300	
GENERAL PURPOSE WORK STATION (A004)	1-7, 11, 12, 14, 16, 23	DESIGN	325	2	500	
SMALL MASS MEASUREMENT (J006)	1-7, 11, 12, 18	COMPLETE	17	0.04	15	X
BIOTELEMETRY SYSTEMS (A010)	6, 10, 19	FABRICATION	36	0.026	NIL	
DISSECTION MICROSCOPE (A006)	1-3, 5, 11, 12, 14, 21	DESIGN	18	0.1	60	
RADIATION DOSIMETER (A017)	8, 9	DESIGN	3.9	0.006	14	
VARIABLE GRAVITY CENTRIFUGE	1, 2, 4, 7, 12, 14, 19	CONCEPTUAL	830	3	1100	
VESTIBULAR RESEARCH FACILITY	6, 23	CONCEPTUAL	830	3	2300	
LINEAR SLED	6, 23	CONCEPTUAL	260	7	TBD	
FREEZER (-30°C) (J044)	1-5, 7, 11, 12, 16	DESIGN	70	0.3	200	
INCUBATOR	17, 12	CONCEPTUAL	36	0.13	80	
RACK MOUNTED CENTRIFUGE (J003)	1, 2, 3, 11, 12, 22	COMPLETE	30	0.08	TBD	X
GAS ANALYZER (J007)	4, 16	COMPLETE	41	0.1	150	X
BLOOD COLLECTION SYSTEM (J005)	1, 2, 3, 11, 12, 22	COMPLETE	8	0.05	NONE	X
PLANT HOLDING FACILITY (SMALL) (PGU)	13-16	COMPLETE	18	0.01	75	
PLANT HOLDING FACILITY (LARGE)	13-16	CONCEPTUAL	200	1	300	

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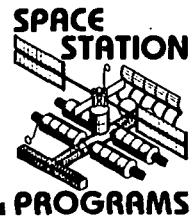


COMMON SUPPORT HARDWARE  
(NONHUMAN) (2)

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The common support hardware listing for the nonhuman laboratory continues here.





## COMMON SUPPORT HARDWARE (NONHUMAN) (2)

HARDWARE REQUIREMENTS	REQUIRED BY EXPERIMENT NUMBER	DEVELOPMENT STATUS	WEIGHT (kg)	VOLUME (cu m)	POWER (W)	HUMAN USE ALSO
METABOLIC CAGE MODULE (RAHF)	3, 4, 21	CONCEPTUAL	2	0.005	2	
NESTING CAGE	7, 11, 12	CONCEPTUAL	2	0.005	NONE	
VIDEO RECORDER	7, 14	DESIGN	11	0.013	14	
ANIMAL SACRIFICING KIT	1, 2, 3, 5, 7, 11, 12, 23	COMPLETE	7	0.001	10	
DISSECTION KIT	1, 2, 3, 5	COMPLETE	2	NIL	NONE	
MINI OSCILLOSCOPE (J001)	19, 23, 24	COMPLETE	1.9	0.003	BATTERY	X
MICRO COMPUTER (J002)	23	COMPLETE	10	0.03	8	X
MULTI-CHANNEL STRIP RECORDER (J018)	23	CONCEPTUAL	30	0.09	500	X
CASSETTE DATA RECORDER (J045)	19, 23, 24	COMPLETE	NIL	NIL	BATTERY	X
EVENT TIMER (J047)	23	COMPLETE	0.2	NIL	BATTERY	X
EMG MONITOR AND SIGNAL CONDITIONER	18, 24	COMPLETE	0.06	NIL	BATTERY	X
GEOSTAT/CLINOSTAT	25	CONCEPTUAL	TBD	0.1	TBD	
BIO SPECIMEN TEST APPARATUS (J009)	14, 21	COMPLETE	10	0.012	16	
BIO/RADIOLOGICAL CONTAINER (J020)	8, 9	CONCEPTUAL	12	TBD	NONE	
GENERAL PURPOSE TEMP RECORDER	4, 19	COMPLETE	NIL	NIL	BATTERY	
UTENSIL/HAND CLEANING FIXTURE (J012)	1-7, 11, 12, 18, 21-24	PROTO COMPL	27	1.0	375	X
POCKET VOICE RECORDER (J013)	20	COMPLETE	0.3	NIL	BATTERY	X
ELECTRODE IMPEDANCE METER (J032)	6, 23	COMPLETE	NIL	NIL	BATTERY	X
MINI SPECTROPHOTOMETER (J048)	4, 20	COMPLETE	0.46	0.0007	BATTERY	X

90-DAY RAHF CONCEPT  
(12-RODENT CAPACITY)

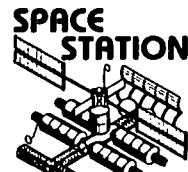
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An example of the type of modifications required to upgrade life sciences equipment developed for Spacelab to a configuration compatible for a space station is presented. Current RAHF hardware is designed to support specimens for a 2-week period and its feeders must be reloaded manually every 4 days. The proposed modifications provide for a 90-day capability without operator intervention.

The primary modifications involve development of an increased-capacity animal feeder containing a 90-day food supply that could interface directly with the cages. In the case of a rodent RAHF, this modification required reducing the number of cages that could be housed in a single rack by a factor of two. The increased capacity feeders are mounted adjacent to the cages.

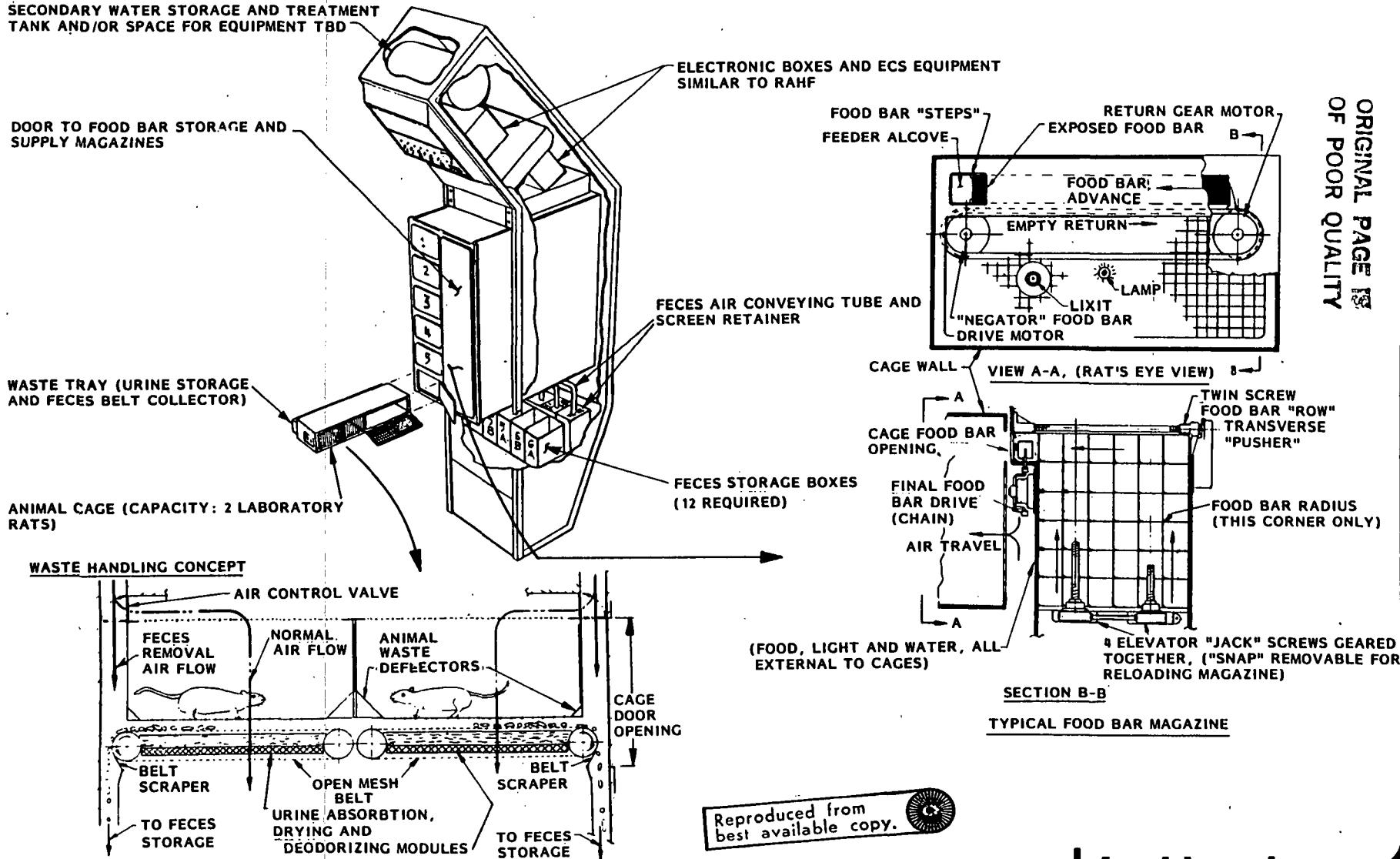
Increased water storage is accomplished by tankage under the space station floor. Automation of waste tray cleanup is required and is accomplished using the waste handling concept shown, which delivers the waste to storage containers in the lower portion of the rack. Humidity condensate is stored in the water tanks, separated by a bladder from the potable water.





# 90-DAY RAHF CONCEPT (12-RODENT CAPACITY)

SECONDARY WATER STORAGE AND TREATMENT  
TANK AND/OR SPACE FOR EQUIPMENT TBD



EXPERIMENT LIST FOR STRAWMAN RESEARCH FACILITY

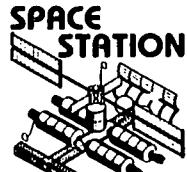
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For the purpose of illustration, a strawman research facility has been developed for a mission where a life sciences research facility is attached permanently to the space station. At intervals of 90 days, life scientists visit the station and conduct required research for periods up to 10 days. The visiting experimenters bring new plants and animals as required and carry back specimens for postflight analysis.

The beginning point for developing this facility was selection of a group of experiments requiring periodic manned intervention that are considered to have a high scientific benefit. These candidates are listed in the chart.

The next step is to determine the number of specimens required per experiment. This assessment includes the degree of allowable animal sharing and unique environments to which the specimens will be exposed. Individual environmental requirements reveal some animal sharing conflicts in terms of g levels, but otherwise extensive sharing should be possible. The adjacent table lists the experiments, species to be used, and g levels required. A total of 21 rats, four squirrel monkeys, and four rhesus monkeys will be exposed in zero g vivaria. Twenty-one rats will be exposed to one g, and 12 rats will be exposed to fractional g's in the variable gravity research centrifuge.





## EXPERIMENT LIST FOR STRAWMAN RESEARCH FACILITY

<u>NUMBER</u>	<u>TITLE</u>	<u>SPECIMEN</u>
1	CALCIUM HEMATOSIS	RAT
2	MUSCLE FUNCTION	RAT
4	METABOLISM	RAT
5	VESTIBULAR PHYSIOLOGY	RAT
10	CARDIOVASCULAR	RHESUS
13	PLANT DEVELOPMENT	ARABIDOPSIS, CARROT, PINE & BEAN
15	CELSS (SEEDLINGS)	RADISH
17	CELSS (CELLS)	CHLORELLA
19	BIORHYTHMS	SQUIRREL MONKEY
21	CELLULAR & TISSUE REPRODUCTION	RAT
25	PLANT GEOTROPISM	CARROT

### SPECIMEN REQUIREMENTS FOR STRAWMAN EXPERIMENTS

<u>EXPER. NO.</u>	<u>SPECIES</u>	<u>TOTAL QUANTITY</u>	<u>QUANTITY AT ZERO G</u>	<u>QUANTITY AT ONE G</u>	<u>QUANTITY AT FRACTIONAL G</u>
1	RAT	42	21	21	
2	RAT	42	21	21	
4	RAT	12	6	6	
5	RAT	24	12		
10	RHESUS	4	4		
13	PLANT				
15	PLANT				
17	CELLS				
19	SQUIRREL MONKEY	4	4		
21	RAT	4	4		
25	PLANT	4	4		

 Lockheed

STRAWMAN NONHUMAN RESEARCH FACILITY

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The foregoing data provided the basis for the general arrangement of the Strawman Nonhuman Research Facility. This example assumes that the carrier tradeoff indicated use of a Spacelab long module and that maximum use of existing hardware is optimum. A flight system/mission assumption is made in favor of an early manned space station where the onboard crew is involved in the Life Sciences activity only in the event of an equipment malfunction.

Based on the previous data on 90-day vivarium capacities, two rodent, one small primate, and four large-primate single-rack holding facilities would be required in the vivarium portion of the research facility. The centrifuge and the two plant holding facilities also would be located in the vivarium area.

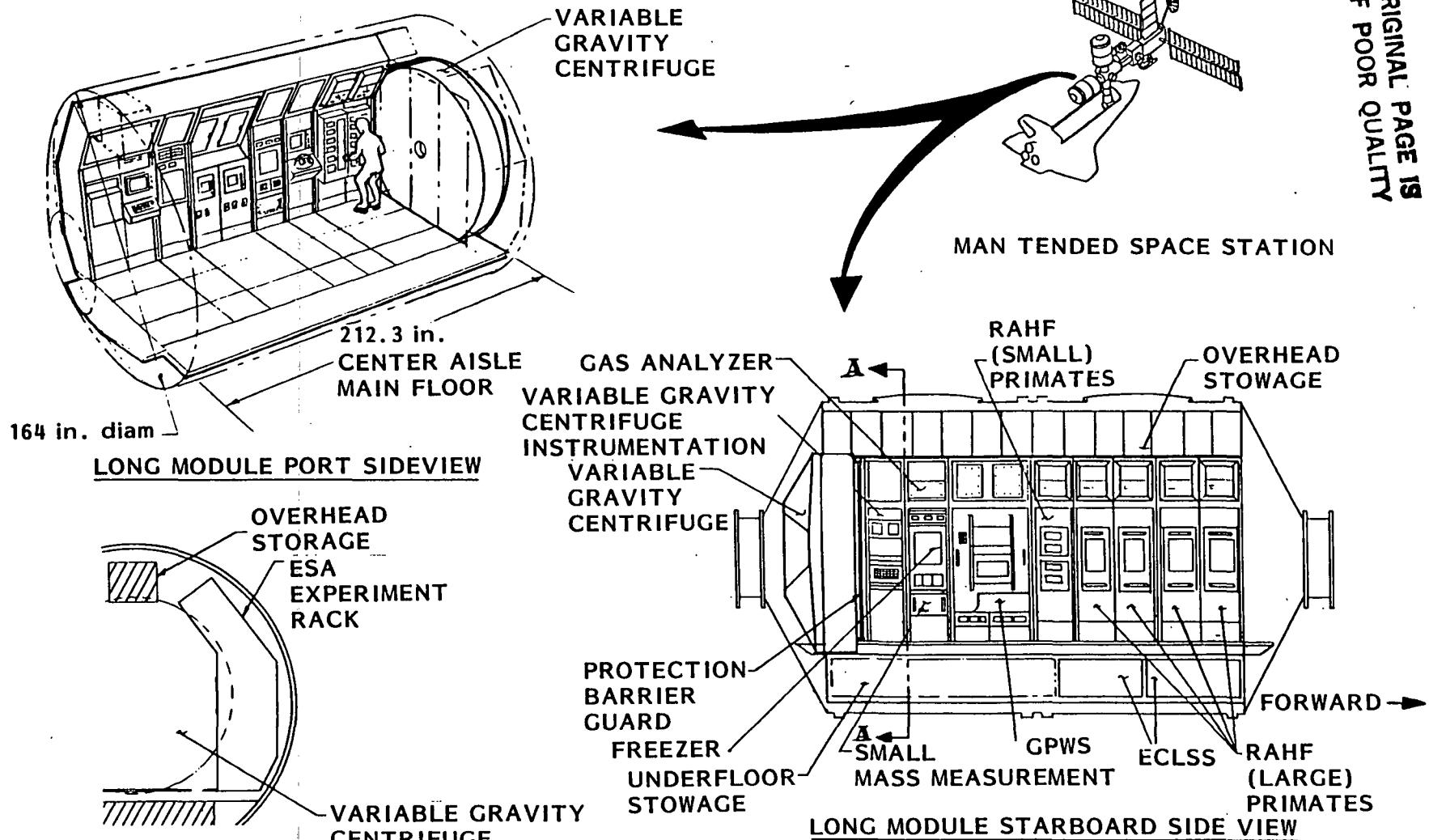
The general arrangement is responsive to the experiment requirements and allows a smooth workflow with adequate accessibility.





# STRAWMAN NONHUMAN RESEARCH FACILITY

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HUMAN EXPERIMENTS MATRIX

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A review of experiments involving humans as subjects was carried out in the same manner as for the nonhuman experiments. The results of this review include the experiments identified by NASA as well as other experiments defined as a result of the user survey. One of the key new experiments is in the area of human capability (experiment no. 12). Several people interviewed, especially within the Air Force, expressed the feeling that one of the major life sciences research areas should be to determine the capability of humans in the zero gravity environment. This should be done for tasks that are expected to be carried out by civilian as well as military crews.





LMSC-D889718

## HUMAN EXPERIMENTS MATRIX

EXPERIMENTS IDENTIFIED BY NASA HEADQUARTERS	NO.	DISCIPLINE									PRIORITY		CREW TIME REQUIREMENT (HOURS/SAMPLE/DAY)	EXPERIMENT UNIQUE HARDWARE	DATA REQUIREMENT	
		CARDIOVASCULAR	MUSCULOSKELETAL	HEMATOLOGY	IMMUNOLOGY	NEUROSENSORY	METABOLISM	BIOENGINEERING	SOLVES PROBLEM	REQUIRES 0 "g"	REQUIRES LONG EXPOSURE	REQ MANNED INVOLVEMENT	POTENTIAL TERR BENE			
		DURING FLIGHT	POST-FLIGHT													
	1. CENTRAL HEMODYNAMICS AND CARDIOVASCULAR REFLEX REGULATION	X								X	X	0.75			NONE REQUIRED	dc-50 Hz
	2. CRANIAL AND CEREBRAL CIRCULATION	X								X	X	0.50			NONE REQUIRED	TBD
	3. ORTHOSTATIC INTOLERANCE	X	X							X	X	4.00			COUNTER PRESSURE CAR.	TBD
	4. DIRECT MEASUREMENTS OF CALCIUM LOSS	X	X			X	X			X	X	0.75			NONE REQUIRED	TBD
	5. MINERAL AND NUTRIENT BALANCE	X	X							X	X	1.50			URINE AND FECAL STORAGE CONTAINERS	TBD
	6. BIOCHEMICAL AND HORMONAL MEASUREMENTS	X								X	X	1.50			URINE AND FECAL STORAGE CONTAINERS	TBD
	7. POSTFLIGHT BIOPSY <sup>(1)</sup>	X								X	X	1.50			NONE REQUIRED	TBD
	8. EFFECTIVENESS OF COUNTER MEASURES	X	X							X	X	0.25	1.50		NONE REQUIRED	TBD
	9. CONFIRMATION OF RED CELL MASS DECREASES AND RED CELL SHAPE			X						X	X	0.50	1.00		NONE REQUIRED	TBD
	10. KINETICS OF OTHER BLOOD CELLS			X						X	X	0.50	2.00		NONE REQUIRED	TBD
	11. POSTFLIGHT BLOOD CELL ANALYSIS IMPROVED METHOD			X	X					X	X	1.00	2.00		NONE REQUIRED	TBD
OTHER EXPERIMENTS	12. BEHAVIOR AND PERFORMANCE	X								X	X	1.00	2.00		NONE	TBD
	13. EXERCISE PHYSIOLOGY	X	X	X		X		X	X	X	X	1.00	2.00		NONE	TBD
	14. MUSCLE LOSS	X			X		X	X	X	X	X	-	2.00		NONE	TBD
	15. ANTHROPOMETRIC MEASURES	X		X	X	X		X	X	X	X	0.75	0.75		MEASUREMENT DEVICE	TBD
	16. IMMUNOLOGY			X				X	X	X	X	1.00	1.00		NONE	TBD
	17. VESTIBULAR SENSITIVITY			X				X	X	X	X	1.00	1.00		NONE	TBD
	18. SPATIAL ORIENTATION/HUMAN CONTROL			X				X	X	X	X	1.00	1.00		NONE	TBD
	19. RADIATION DOSIMETRY			X				X	X	X	X	1.00	-		NONE	TBD
	20. AUDITORY SENSITIVITY			X				X	X	X	X	0.50	0.50		NONE	20-20K Hz

(1) PROBABLY NOT ALLOWED ON HUMAN SUBJECTS

 Lockheed

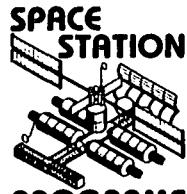
COMMON SUPPORT HARDWARE  
(HUMAN) (1)

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Common laboratory equipment has been listed for use in the human life sciences laboratory. The items are needed to support the candidate experiments and do not reflect the equipment required to support the health maintenance facility. Some of the items listed, however, could be shared with the Health Maintenance Facility and even with the nonhuman research facility.

The equipment items are cross-referenced with the individual experiments. The development status of the equipment is defined. Where the equipment is being developed for Spacelab, the appropriate NASA JSC designation is provided. In general, items developed for Spacelab can be used directly in a Space Station Life Sciences Research Facility with little or no modification. Weight, volume, and power estimates of these equipment items also are presented.





## COMMON SUPPORT HARDWARE (HUMAN) (1)

FACILITY REQUIREMENTS	REQUIRED BY EXPERIMENT NUMBER	DEVELOPMENT STATUS	WEIGHT (kg)	VOLUME (cu m)	POWER (W)	ALSO REQUIRED FOR NON-HUMAN LIFE SCI LAB
ECHOCARDIOGRAPH (J046)	1, 12, 13	CONCEPTUAL	90	0.2	450	
BLOOD PRESSURE AND ECG (PHYSIOLOGICAL MONITORING SYSTEM PMS) (J008)	1, 2, 3, 12, 13	DESIGN	10	0.9	10	
PLETHYSMOGRAPH, LIMB (J023)	1, 13	FABRICATION	1.2	0.0004	BATTERY	
LOWER BODY NEGATIVE PRESSURE SUIT (J033)	1, 3, 13	PROTOTYPE COMPLETE	20	0.15	50	
RETINAL PHOTOGRAPH	2, 13, 14	NONE	TBD	TBD	TBD	
OCCULAR TONOMETER	2, 13	NONE	TBD	TBD	TBD	
INDIRECT PRESSURE RETINAL VESSELS	2	NONE	TBD	TBD	TBD	
DIRECT CALCIUM MONITOR (PHOTON AB, ACTIVATION, TOMOGRAPHY)	4, 13	NONE	TBD	TBD	TBD	
URINE SAMPLING AND STORAGE	5, 6, 16, 13	DESIGN	15	0.02	50	
FECAL SAMPLING AND STORAGE	5, 6, 16, 13	CONCEPTUAL	TBD	TBD	TBD	
REFRIGERATOR FREEZER (J044)	6, 8, 10, 11	DESIGN	70	0.30	200	
RACK MOUNTED CENTRIFUGE (J003)	6, 7, 10, 11, 16	COMPLETE	30	0.08	480	
INFLIGHT BLOOD COLLECTION SYSTEM (J005)	6, 8, 11, 13, 16	COMPLETE	8	0.05	NONE	X
MINIOSCILLOSCOPE (J001)	17, 18	COMPLETE	1.9	0.003	BATTERY	X
MICROCOMPUTER	15, 17, 18	COMPLETE	10.0	0.03	8	X
CASSETTE DATA RECORDER (J045)	15, 17, 18	COMPLETE	NIL	NIL	BATTERY	X
EVENT TIMER	13	CONCEPTUAL	0.2	NIL	BATTERY	X
COMPOUND MICROSCOPE	9	COMPLETE	15.0	0.01	60	X

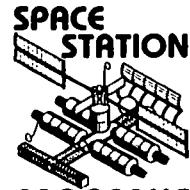


COMMON SUPPORT HARDWARE  
(HUMAN) (2)

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The common support hardware listing for the human laboratory continues here.





## COMMON SUPPORT HARDWARE (HUMAN) (2)

### PROGRAMS

FACILITY REQUIREMENTS	REQUIRED BY EXPERIMENT NUMBER	DEVELOPMENT STATUS	WEIGHT	VOLUME	POWER	ALSO REQUIRED FOR NON HUMAN LIFE SCI LAB
ROTATING CHAIR	17, 18	COMPLETE	100	1.2	1600	
LINEAR SLED	18	CONCEPTUAL	260	7.0	TBD	X
AUDIOMETER	15	CONCEPTUAL	TBD	TBD	TBD	
FAR FIELD POTENTIOMETER	15	CONCEPTUAL	TBD	TBD	TBD	X
EMG MONITOR AND SIGNAL CONDITIONER (J011)	13, 14	COMPLETE	0.06	NIL	BATTERY	X
BICYCLE ERGOMETER (J024)	13	DESIGN	70	0.04	50	
GAS ANALYZER (J007)	12, 13	COMPLETE	41	0.1	150	X
UTENSIL/HAND CLEANING FIXTURE (J012)	1, 5, 6, 9-11	PROTOTYPE COMPLETE	27	1.0	375	X
POCKET VOICE RECORDER (J013)	3, 8, 12, 13, 17, 18, 20	COMPLETE	0.3	NIL	BATTERY	X
HEMATOCRIT CENTRIFUGE (J016)	9-11, 16	COMPLETE	0.83	0.009	BATTERY	
SMALL MASS MEASUREMENT (J061)	TBD	COMPLETE	17	0.04	15	X
BODY MASS MEASUREMENT DEVICE (J017)	15	COMPLETE	39	0.6	15	X
MULTI-CHANNEL STRIP CHART RECORDER (J018)	1-3, 12, 13, 17, 18, 20	CONCEPTUAL	30	0.09	500	X
URINE MONITORING (J027)	4-6, 8, 16, 19	FABRICATION	22	0.04	50	
VENOUS OCCLUSION CUFF	1, 12, 13	FABRICATION	2	0.001	BATTERY	
ELECTRODE IMPEDANCE METER (J32)	1, 3, 12, 13, 17, 18, 20	COMPLETE	NIL	NIL	BATTERY	X
LOW GRAVITY CENTRIFUGE (J043)	9-11, 16	CONCEPTUAL	12	0.04	345	
MINI SPECTROPHOTOMETER (J048)	12, 13	COMPLETE	0.46	0.0007	BATTERY	X
IMAGING/X-RAY	14, 15	CONCEPTUAL	TBD	TBD	TBD	X

## STRAWMAN HUMAN RESEARCH AND HEALTH MAINTENANCE FACILITY (1)

The Human Research and Health Maintenance Facility has been laid out in the equivalent of a three-segment-long Spacelab module with an internal pressurized volume of approximately 4,000 ft. Both manned research and health care are combined within the laboratory which includes the following basic functional areas:

- Basic Health Maintenance
  - Medical/Surgical
  - Dispensary
  - Dental
  - Isolation & Beds
- Human Research
  - Experiment Unique Hardware
  - Common Support Hardware
- Large Airlock
  - EVA Familiarization & Training
  - Suit/PLSS Experiments/ Research
  - EVA Tools/Aids Evaluations
- Exercise Area
  - Medical Monitoring
  - Standard Physical Fitness
  - Hyperbaric Chamber (within airlock)
  - Data Handling/Processing Work Station
  - Maintenance Demonstration Work Bench
  - Assessment/Evaluation & Checkout
  - Techniques & Procedures Development
  - Social-Behavioral Study Area (with privacy)
  - Equipment Arrangement & Layout
  - Tether & restraint
  - Mobility & Locomotion
  - Color/Sound/Texture Research

This facility provides an integral human health care and research program potential isolated from other functional laboratories and/or habitats. Crew members can participate either on the basis of 'off-hours' volunteer duty and/or can be built-up in a modular function as the station evolves. Initial capability will be planned for Health Maintenance (including Dispensary) with other capabilities to follow as a function of station needs and crew size, tied to an increasing experiment/research evolution.

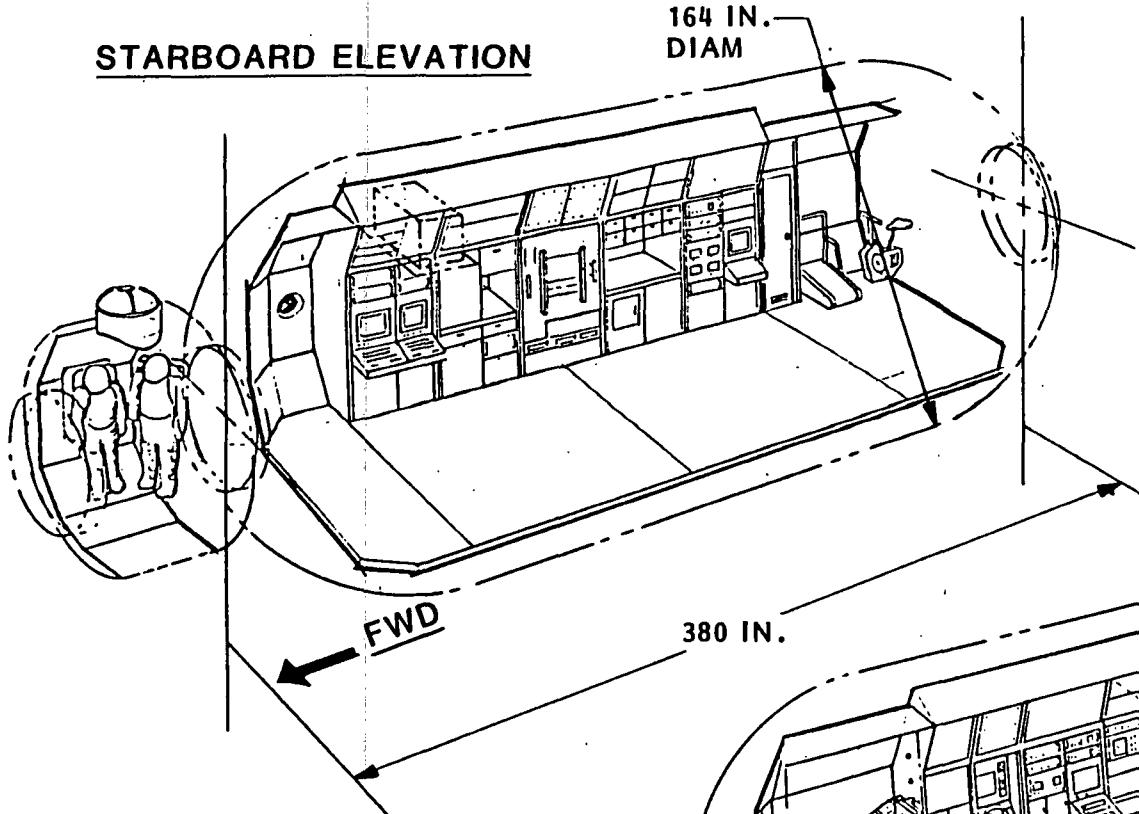
This facility also could be considered for the solar flare radiation shelter, providing the thicker shield over its entire surface.





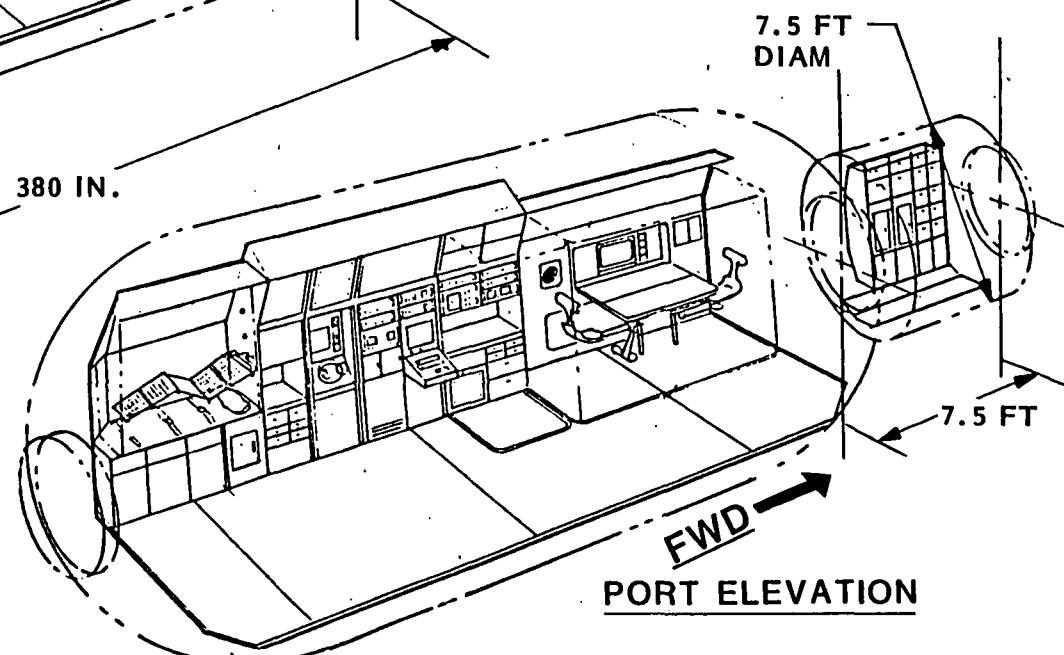
# STRAWMAN HUMAN RESEARCH AND HEALTH MAINTENANCE FACILITY (1)

STARBOARD ELEVATION



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LARGE AIRLOCK



ORIGINAL DRAWING  
OF POOR  
QUALITY

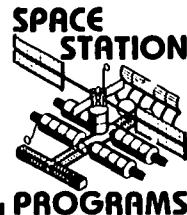
Lockheed

STRAWMAN HUMAN RESEARCH AND HEALTH MAINTENANCE FACILITY (1)

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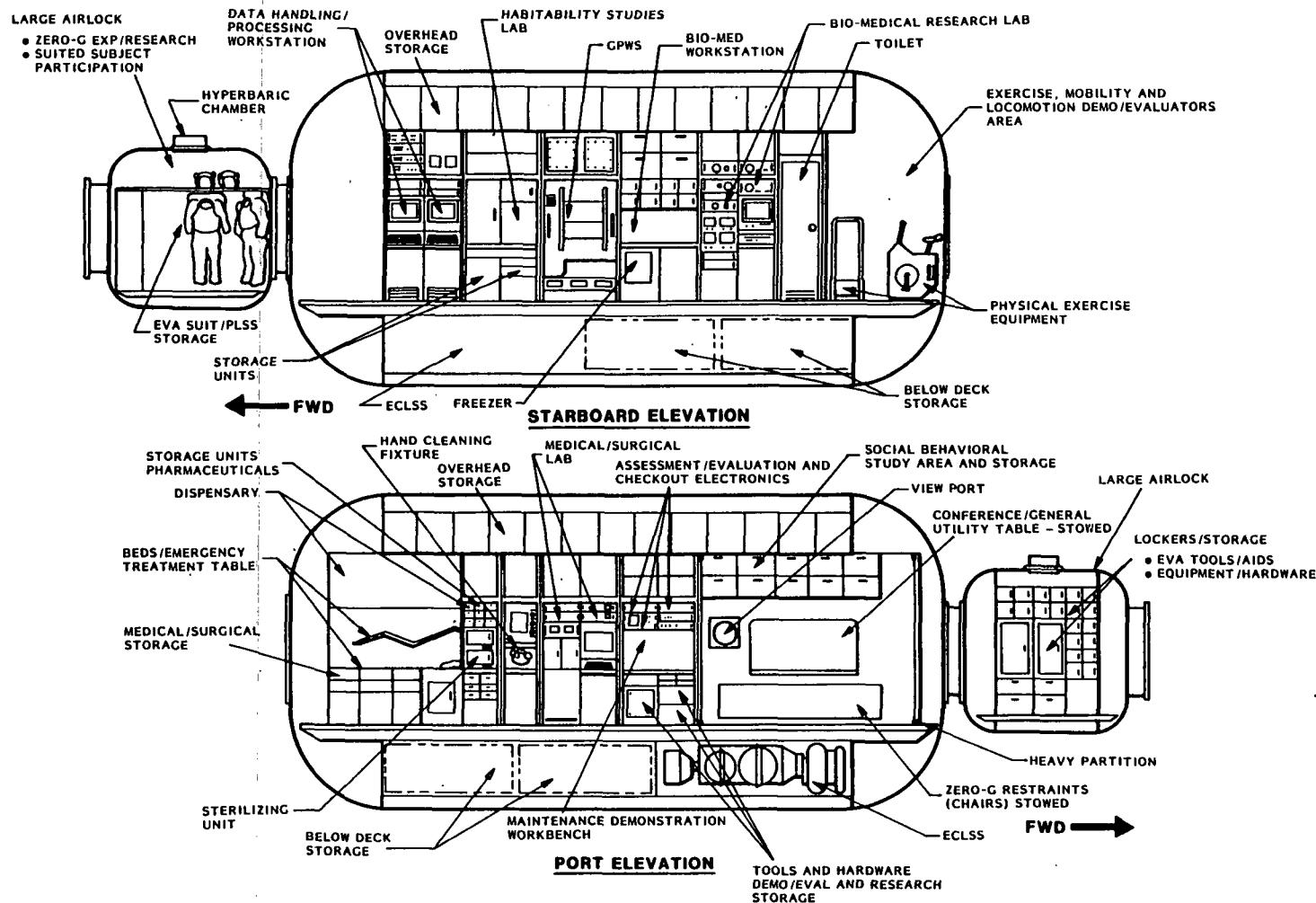
Additional details of this facility are shown in these port and starboard elevations.





# STRAWMAN HUMAN RESEARCH AND HEALTH MAINTENANCE FACILITY (1)

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ARCHITECTURAL CONSIDERATIONS

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The impact of life sciences research on space station architectural considerations is presented for both near-term and long-term situations. Studies to date have concluded that the human research laboratory will evolve from the health maintenance facility, which is justified easily on the basis of the cost of a single rescue mission.

A nonhuman laboratory is needed to allow invasive and prolonged experiments that cannot be conducted on humans. This facility will be separate from the human research laboratory but attached to the station and will contain a shirt-sleeve environment. The large investment in Spacelab equipment cannot be ignored, therefore, space station hardware will be similar to Spacelab hardware where possible.

Plant experiments may be conducted on free flyers but animal experiments will probably not be. There is an advantage to free flyers for plant studies because plant physiologists want low gravity, e.g.,  $10^{-4}$  g or less and no disturbances such as crew movements or docking. However, automating an animal experiment to be flown on a free flyer would be extremely costly.

In the long term there are two significant areas where life sciences considerations may have a major impact on the architecture of a space station. These are in the areas of radiation shielding and artificial gravity. A space station at geosynchronous orbit or a space settlement requires considerable shielding to reduce radiation to near terrestrial levels.

The issue of artificial gravity has not been completely laid to rest. The end point of some physiological phenomena such as calcium loss has not been determined and future research may establish that artificial gravity is required. This could have a significant impact on the configuration of a space station.





## ARCHITECTURAL CONSIDERATIONS

### NEAR TERM

- HUMAN RESEARCH LABORATORY WILL EVOLVE FROM HEALTH MAINTENANCE FACILITY
- HEALTH MAINTENANCE FACILITY EASILY JUSTIFIED ON BASIS OF COST OF RESCUE MISSION
- NONHUMAN LABORATORY NEEDED TO ALLOW INVASIVE OR PROLONGED RESEARCH REQUIRED FOR FURTHER UNDERSTANDING OF BIOLOGICAL EFFECTS OF SPACE
- NONHUMAN LABORATORY WILL BE SEPARATE FROM HABITATION MODULE, BUT ATTACHED TO SPACE STATION
- LARGE INVESTMENT IN SPACELAB EQUIPMENT CANNOT BE IGNORED
- PLANT EXPERIMENTS MAY BE CONDUCTED ON FREE FLYERS, BUT ANIMAL EXPERIMENTS WILL NOT

### FAR TERM

- LIFE SCIENCES CONSIDERATIONS COULD BE MAJOR DRIVER ON LONG DURATION MISSIONS
  - RADIATION SHIELDING
  - ARTIFICIAL GRAVITY



RADIATION CONSIDERATIONS

---

The life science considerations related to radiation are restricted to crew impacts. The concerns are to assure satisfactory crew performance and to prevent both immediate and late health effects.

There are five main radiation hazards.. By far the most dangerous are solar flares, which can result in radiation levels near Earth that are extremely intense and penetrating, and can be lethal. Their occurrence is unpredictable but generally follows the 11-year solar cycle. Five to nine events per year can be anticipated. Galactic cosmic rays are present to a colony at L-5 or on an interplanetary mission, the radiation levels are higher.

The Earth's magnetic field traps cosmic radiation in belts (i.e., the Van Allen belts) of varying intensity. At low altitudes the radiation varies enormously during an orbit, with peaks occurring over the South Atlantic/South American anomaly. Data must be integrated over many orbits to determine doses.

Calculation of dosage must take into account many factors, including consideration of the body's ability to repair some radiation damage.





PROGRAMS

## RADIATION CONSIDERATIONS

- CREW
  - SHOULD NOT IMPAIR ABILITY TO CARRY OUT FLIGHT TASKS
  - SHOULD NOT CAUSE MAJOR EXPRESSED SOMATIC CHANGES
  - SHOULD NOT CAUSE LATE EFFECTS
- HAZARD SOURCES
  - SOLAR FLARES:
    - AT RANDOM INTERVALS
    - 11 YEARS BETWEEN MAXIMUM & MINIMUM
  - GALACTIC COSMIC RAYS:
    - LIGHT AND HEAVY NUCLEI
    - SOME PROTECTION FROM EARTH'S MAGNETIC FIELD
  - GEOMAGNETICALLY TRAPPED RADIATION (VAN ALLEN BELTS)
    - POLAR AND GEOSYNCHRONOUS ORBITS WORSE THAN EQUATORIAL (TO 30°) LEO
  - SECONDARY EMISSIONS
  - NUCLEAR POWER SUPPLIES
- CALCULATION OF DOSAGE
  - REVERSIBLE AND IRREVERSIBLE PORTIONS OF RADIATION DAMAGE
  - DOSE EQUIVALENT (DE) (REMS)= $D \times TF \times DF \times QF \times SF \times IF$
  - DOSE LEVEL (D) (RADS) (1 RAD = 100 ERGS/G)
  - TIME FACTOR (TF)
  - DISTRIBUTION FACTOR (DF) - OF ABSORBED DOSE IN BODY
  - QUALITY FACTOR (QF) - IN RELATIVE BIOLOGICAL EFFETIVENESS (RBE). CONSIDERING LINEAR ENERGY TRANSFERS (LET)
  - SPACE FACTOR (SF) - TYPE OF RADIATION, WEIGHTLESSNESS, AND OTHER ENVIRONMENTS
  - INDIVIDUAL FACTORS (IF) INCLUDING AGE

SHIELDING CONSIDERATIONS

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Shielding requirements depend on many factors. A starting point is a model of the environment through which the space station will be orbiting. Even today, these models are subject to uncertainty due to lack of sufficient data and the uncertainty of events including magnetic storms and substorms as well as solar activity. Lockheed has developed many models of the environment and flux programs for use in dose versus shielding calculations and analyses.

Orbital characteristics are important due to the geomagnetic belts. In low-altitude, low-inclination orbits the daily dose is small and shielding is much more effective against electrons than protons. As inclination increases, the dose rate at low altitude increases. Dose rates increase sharply and steadily as altitude increases from the top of the atmosphere to several thousand kilometers, then decrease sharply as orbit increases beyond the trapping region to GEO or beyond. To meet the Apollo limit of 25 rem, an astronaut could stay in a low altitude LEO under a  $1\text{g/cm}^2$  aluminum shield for nearly one year. In low polar orbit with the same shield, the same dose occurs in 20 days. In the core of the belt at 4,000 km, same shield, equatorial orbit, the dose is reached in about one hour.

Shielding can be approached in many ways from full protecting thick shields, to thin with escape shelters for solar events, to partial shielding of critical areas of the body.





## SHIELDING CONSIDERATIONS

- MODELS OF SPACE RADIATION ENVIRONMENT
- SPACE STATION ORBITAL CHARACTERISTICS
  - INCLINATION - POLAR; EQUATORIAL TO APPROX. 30°
  - SHAPE - CIRCULAR; ELLIPTIC
  - ALTITUDE - LEO; GEO
- MISSION DURATION
- SHIELDING APPROACH ALTERNATIVES
  - FULL PROTECTION - ALL EVENTS
  - PARTIAL SHIELDING OF CRITICAL ORGANS & SYSTEMS - E.G., EYES, MARROW
  - SAFE HAVENS (SHELTER) FROM SOLAR FLARES
  - USE OF FUEL RESERVES, PROVISIONS, MACHINERY, AND OTHER EQUIPMENT

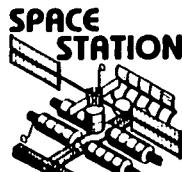
RADIATION SHIELDING DESIGN CRITERIA

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Today, only passive shielding alternatives based on shield mass are viable. Active shields such as plasma fields are promising, while electric or magnetic fields currently are well beyond feasibility. In calculating shield thickness, the aluminum reference of 0.15 inches = 1.0 g/cm<sup>2</sup> is a convenient concept. To match the shield of the Earth's atmosphere would require a 12.5 foot thickness of aluminum.

Dosage allowables vary widely with philosophy. The U.S. Government allows 0.5 rem/yr for effects of a radiation source on the general population and 5.0 rem/yr for workers in a radiation environment. For reference, the natural dose at sealevel is about 0.1 rem/yr. NASA established the numbers shown for Apollo, while Soviet numbers are higher. Soviet interplanetary allowances are similar to the recommendations used in the Manned Orbital Systems Concepts (MOSC) study. The Space Settlements study recommended the conservative U.S. Government Earth standards. Shielding associated with these limits is shown in the far right column. For the space colony general population, a shield of nearly 7' of aluminum is required. For the MOSC space station, a skin of 0.15 inches of aluminum plus a flare shelter of 3.15 inches of aluminum would meet the recommendations for low inclination LEOs.





## RADIATION SHIELDING DESIGN CRITERIA

- PASSIVE SHIELDING
  - EARTH REFERENCE IS 1.000 G/CM<sup>2</sup>
  - 0.15 IN. OF ALUMINUM PROVIDES 1.0 G/CM<sup>2</sup>
- ACTIVE SHIELDING (CONCEPTUAL)
  - PLASMA, MAGNETIC, OR ELECTRIC FIELDS
- DOSAGE ALLOWABLES - VARIOUS SOURCES

<u>CATEGORY</u>	<u>U.S. GOVER.</u>	<u>SOVIET</u>	<u>SPACE SETTLEMENTS</u>	<u>MOSC</u>	<u>SHIELD REQUIRED</u>
GENERAL POPULATION	0.5 REM/YR		0.5 REM/YR		550 G/CM <sup>2</sup> (SS)
RADIATION WORKERS	5.0 REM/YR		5.0 REM/YR		280 G/CM <sup>2</sup> (SS) & SHELTER
EARTH ORBIT					
- ALLOWED	25 REM (APOLLO)	15 REM (30 DAYS)			
- JUSTIFIED RISK	-	50 REM (30 DAYS)			
- CRITICAL	50 REM ( " )	125 REM (30 DAYS)			
SPACE STATION					
- 90 DAYS				105 REM	1 G/CM <sup>2</sup> (MOSC)
- 1 YEAR				225 REM ( ÷ 2 FOR EYES)	& SHELTER OF 21 G/CM <sup>2</sup>
INTERPLANETARY			200 REM		
- 1 YEAR			250 REM		
- 2 YEARS			275 REM		
- 3 YEARS					

RADIATION RECOMMENDATIONS

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The effects of radiation on man in space are not known, as can be seen from the widely varying dosage recommendations. Research is needed in space to determine the possible synergistic effects of the unique environments of weightlessness and cosmic/solar radiation, neither of which can be duplicated on Earth. Extensive monitoring is needed also due to the variabilities in data and models of the environment. Since some studies recommend flare shelters, and flare warnings leave only a short time after detection, prediction techniques would be very useful. Research on drugs for protection or as countermeasures also could produce very cost effective benefits if shielding could be reduced.

Instrumentation development is recommended for both individual and spacecraft monitoring and research studies. Biomedical diagnostic tests of astronaut condition such as via some new urinalysis technique would add to monitoring capabilities.

R&D in the radiation area is expected to have spin-off benefits in the areas noted.





## RADIATION RECOMMENDATIONS

- RESEARCH - IN SPACE ON RADIobiOLOGIC EFFECTS - HEAVY IONS USING ACCELERATORS (USING ANIMALS)
  - COMBINED EFFECTS OF IONIZING RADIATION AND OTHER FACTORS OF SPACE ENVIRONMENTS
  - MONITORING TO IDENTIFY ANOMALIES, PROVIDE FLAGS FOR OPERATIONAL DECISION MAKING, AND PROVIDE ACCURATE ASSESSMENTS OF RADIATION LEVELS ON EARLY MISSIONS
  - ON RADIATION PROGNOSIS, PARTICULARLY SOLAR ACTIVITY
  - ON RADIOPROTECTIVE DRUGS AND OTHER DEVICES
- DEVELOPMENT
  - SPECIAL INSTRUMENTATION
  - ONBOARD AND INDIVIDUAL DOSIMETERS
  - CONTINUOUS MONITORING AND CHARACTERIZATION OF SPACE RADIATION
  - SPECIFIC DIAGNOSTIC TESTS OF ASTRONAUT CONDITION
- BENEFITS
  - AID IN DETERMINING TOLERANCE OF MAN TO PROLIFERATING RADIATION SOURCES ON EARTH, AS WELL AS COUNTERMEASURES AND INSTRUMENTATION

ARTIFICIAL GRAVITY CONSIDERATIONS

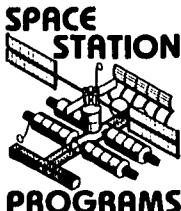
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Because of health and performance problems associated with weightlessness, some level of artificial gravity may be desirable and may be required in long-term space stations. Known health problems include bone demineralization, which has no known end point or zero-gravity countermeasure. A lesser problem is space sickness to which adaptation occurs normally within a few days and always, so far, within one week. Cardiovascular deconditioning, hormone and electrolyte imbalances, and muscle loss all are persistent manifestations of zero gravity. Performance degradations also are known to occur. Locomotion is difficult, and balance and material handling are abnormal.

If rotation is used to provide a level of artificial gravity, its physical effects must be considered in the design. These include Coriolis effects that change the g-level with perpendicular linear movements and cross-coupled angular accelerations associated with body and head movements. Gravity gradient could be important in very short radius systems. Motion sickness could be evoked by head movements or transitions from weightless sections of the craft to artificial gravity areas.

Tether concepts should be explored since these produce a linear artificial gravity field. The tether length to produce gravity levels above 0.05g may be impractical from operational considerations, however.





## ARTIFICIAL GRAVITY CONSIDERATIONS

- HEALTH PROBLEMS OF NO GRAVITY
  - BONE DEMINERALIZATION - NO KNOWN END POINT
  - SPACE SICKNESS - ADAPTATION WITHIN ONE WEEK
  - CARDIOVASCULAR DECONDITIONING - PERSISTENT
  - HORMONE AND ELECTROLYTE IMBALANCES - PERSISTENT
  - MUSCULAR ATROPHY - PERSISTENT
- HUMAN PERFORMANCE
  - SELF LOCOMOTION
  - MATERIAL HANDLING
  - TRANSITION FROM ARTIFICIAL GRAVITY TO WEIGHTLESSNESS
  - POSTURAL BALANCE
- PHYSICAL EFFECTS OF ROTATION
  - CORIOLIS - CROSS COUPLED ANGULAR ACCELERATIONS
    - MOTION SICKNESS
  - GRAVITY GRADIENT
    - TETHER CONCEPT AVOIDS THESE PROBLEMS

ARTIFICIAL GRAVITY DESIGN CRITERIA

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Criteria for artificial gravity design are many, opinions are varied, and facts are missing. Thus, LMSC is providing some of the views of various investigations over the past 20 years. There is as yet no right answer to the design criteria question.

In the area of health problems, no criteria can be established, other than normal Earth gravity, for the g level needed because no hypogravity studies have been conducted. A variable-gravity research centrifuge as part of a space station life sciences research facility is needed to determine whether two-tenths g, for example, or some other level is needed to prevent bone loss, etc.

For physical and performance considerations, many views have been offered. In the first Symposium on The Role of the Vestibular Organs in the Exploration of Space in 1965, Allen Thompson of GE suggested that Coriolis force not exceed 20 percent, that rotation rate not exceed 6 rpm due to head motion (sickness) considerations, and that 0.28 g be provided for normal locomotion. At the fifth and last such symposium in 1970, Ralph Stone of NASA LaRC summarized work in the area with other selected criteria. The Space Settlements study in 1975 concluded so little was known that the only answer was to provide Earth standard gravity and an essentially nonperceptible rotation rate of 1 rpm. The implications on radius of these criteria vary from 48 feet to over half a mile.





LMSC-D889718

## ARTIFICIAL GRAVITY DESIGN CRITERIA

- FOR HEALTH: NO CRITERIA ESTABLISHED

- FOR PHYSICAL & PERFORMANCE:

	STONE	THOMPSON	SPACE SETTLEMENTS STUDY
CORIOLIS	- $\Delta W/W \leq 25\%$ $V @ 4 \text{ RPM}$	$\leq 20\%$	-
HEAD MOTION	- 6 RPM	6 RPM	-
GRAVITY GRADIENT	- MAN-NO PROBLEM OBJECTS-0.5G FOR 2M		
LOCOMOTION (MIN)	- WALKING 0.8G CLIMBING 0.1G	0.28G	-
MATERIAL HANDLING	- 0.2G	-	-
GENERAL HABITATION	- -	-	1 G - 1 RPM
• IMPLIED RADIUS BASED ON CORIOLIS	- 50' @ 0.27G	48' @ 0.58G	2,900'

DESIGN CRITERIA FOR EFFECTIVE HUMAN  
PERFORMANCE IN ROTATING SPACE STATION

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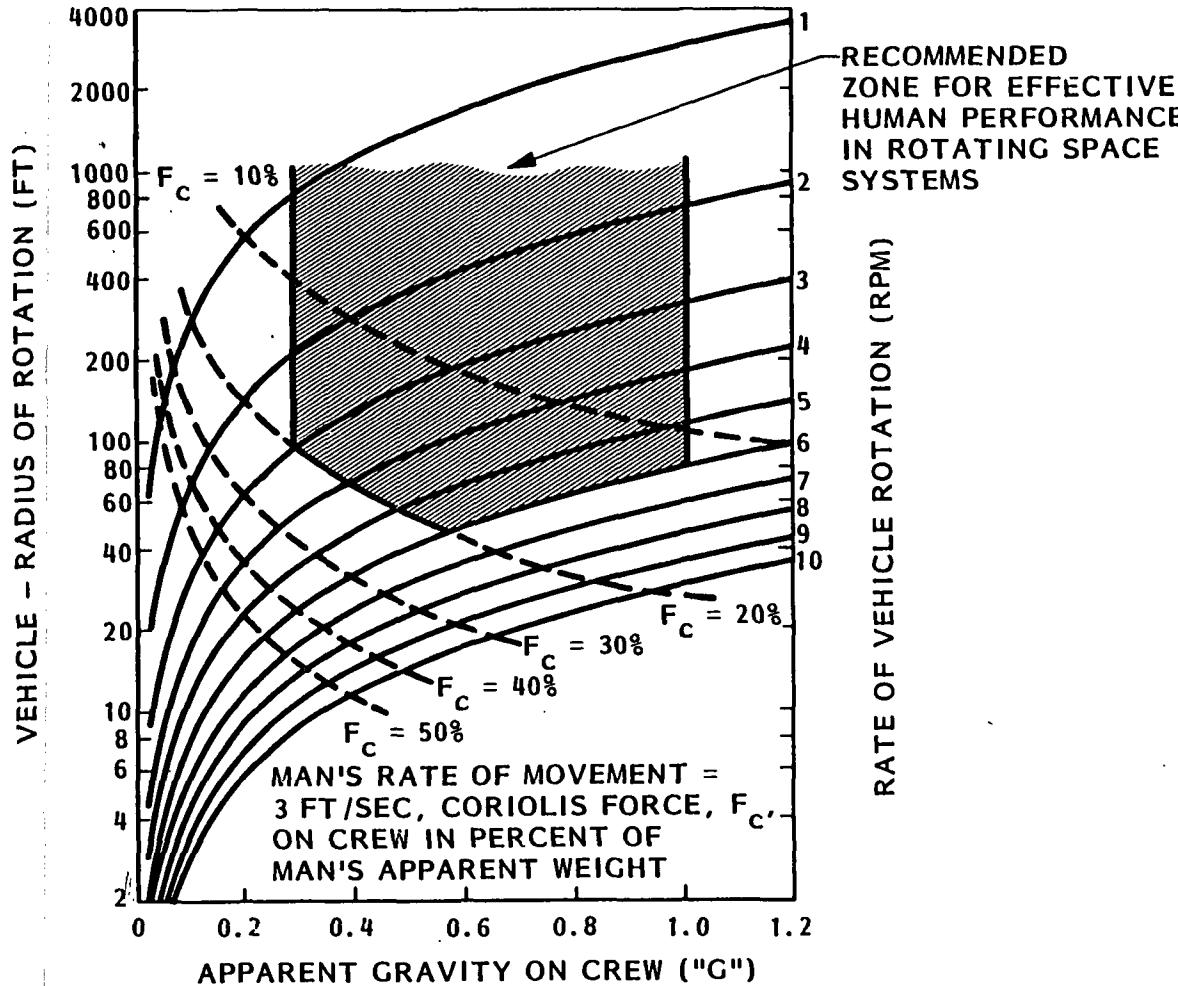
A graphic summary of Thompson's criteria for artificial gravity shows several boundary limits. The vertical lines on the left and right represent the g limits of 0.28 minimum for locomotion and 1.0 for Earth standard. Curves of rotation rate versus g show the 6 rpm ceiling and curves of Coriolis force, Fc, show the 20 percent ceiling. The knee in this chart for minimum radius occurs at 48 feet.





LMSC-D889718

## DESIGN CRITERIA FOR EFFECTIVE HUMAN PERFORMANCE IN ROTATING SPACE STATION



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RECOMMENDATIONS REGARDING ARTIFICIAL GRAVITY

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The artificial gravity requirement is very ill-defined at this time. Most investigators feel it is going to be needed, but rotation rates and g-levels are subject to widely differing opinions.

A research program is needed, and must be conducted in the weightless space environment to produce meaningful results. The major tool for the research is a variable gravity centrifuge. This has been planned by NASA for the dedicated Life Sciences Spacelabs, although no budget authority has been provided to proceed with flight hardware. Information from Spacelab is needed to plan further studies in space station facilities, ultimately leading to a design decision on artificial gravity.





## RECOMMENDATIONS REGARDING ARTIFICIAL GRAVITY

- RESEARCH IS REQUIRED IN SPACE ON
  - ROTATION RATES - HUMAN ADAPTATION, LONG-DURATION HABITABILITY, TRANSITION EFFECTS BETWEEN ROTATING AND NONROTATING AREAS
  - G-LEVEL VARIATIONS - ASSOCIATED WITH RADIAL MOVEMENTS - CONTINUOUS AND STEPPED
  - LOW-G TOLERANCE - LONG-TERM PHYSIOLOGICAL EFFECTS OF ZERO AND FRACTIONAL G-LEVELS
- A LARGE-RADIUS RESEARCH CENTRIFUGE SHOULD BE GIVEN URGENT PRIORITY FOR THE SECOND DEDICATED LIFE SCIENCES SPACELAB (SL-10) AND SUBSEQUENT FLIGHTS.
- THE SPACE STATION SHOULD INCLUDE CAPABILITY FOR RESEARCH IN ROTATIONAL HYPOGRAVITY, BOTH WITH HUMAN AND NONHUMAN SUBJECTS.
- SYSTEM STUDY AND EXPERIMENTS ARE REQUIRED ON LINEAR ARTIFICIAL GRAVITY FIELD. (TETHER SYSTEM).

## POTENTIAL BENEFITS OF SPACE ACTIVITIES (1)

The LMSC study placed significant emphasis on defining terrestrial benefits to Life Sciences research in space. Many ideas were uncovered; unfortunately, few provide certain benefits at an affordable cost.

In the biomedical area, a number of topics have been suggested where weightlessness provides benefits such as treatment of burn patients where, in effect, they could be levitated to support their weight. However, when the ideas suggested were probed more deeply, they did not stand up. They all seem to suffer from uncertainty in their benefits, but certainty in their high costs.

The research area holds more promise. In the area of plants, gravity gets in the way of understanding plant physiology. If gravity were eliminated, more could be learned about plant biology and this new knowledge could lead to increased crop yields on Earth. Other examples include (1) conducting genetic research too dangerous to do on Earth, (2) a better understanding of calcium loss could lead to the cure of diseases, such as arthritis or osteosclerosis. However, as with most research, the benefits are not defined at the outset.





## POTENTIAL BENEFITS OF SPACE ACTIVITIES (1)

### BIOMEDICAL

- "MAYO CLINIC" IN SPACE

UNCERTAIN BENEFITS AND CERTAIN HIGH COST

### RESEARCH (TYPICAL)

- INCREASED CROP YIELD FROM UNDERSTANDING OF ZERO GRAVITY PLANT PHYSIOLOGY
- GENETIC RESEARCH TOO DANGEROUS TO DO ON EARTH
- UNDERSTANDING OF ZERO GRAVITY PHYSIOLOGY LEADS TO SOLUTION OF TERRESTRIAL DISEASES, E.G., CALCIUM LOSS - OSTEOSCLEROSIS

BENEFITS HAVE NOT BEEN DEFINED AT THE OUTSET



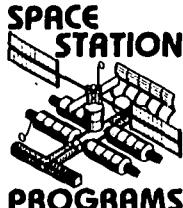
## POTENTIAL BENEFITS OF SPACE ACTIVITIES (2)

There have been significant benefits in the area of equipment spin-off from life sciences activities in space. Some are listed here and future spin-offs can be expected.

In the social area, a number of people believe that space colonization is a solution to some terrestrial problems such as increasing population and increasing demand for resources. To that end, the space station is required to qualify man to be a productive member of a space colony and it defines the parameters for long-term survivability.

An interesting adjunct results from the National Cancer Institute statement that 90 to 95 percent of all diseases are environmentally caused. In a space station there is the opportunity to control completely the environment and examine and exploit this hypothesis.





LMSC-D889718

## POTENTIAL BENEFITS OF SPACE ACTIVITIES (2)

### EQUIPMENT SPIN-OFF (TYPICAL)

- PROSTHETICS
- IMPLANTABLE MEDICATION DELIVERY SYSTEM
- BLOOD FILTERING SYSTEM
- PORTABLE MEDICAL STATUS AND TREATMENT SYSTEM
- HUMAN TISSUE STIMULATOR
- RECHARGEABLE PACEMAKER
- MICROWAVE THERMOGRAPH
- OPHTHALMIC SCREENING DEVICE

### FUTURE SPIN-OFFS CAN BE ANTICIPATED

#### SOCIAL

- DEFINES PARAMETERS FOR LONG-TERM SURVIVABILITY
- IDENTIFIES HEALTH BENEFITS OF COMPLETELY CONTROLLED ENVIRONMENT
- QUALIFIES MAN TO BE A PRODUCTIVE MEMBER OF A SPACE COLONY

### SPACE COLONIZATION VIEWED BY SOME AS SOLUTION TO TERRESTRIAL PROBLEMS

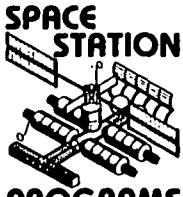
 Lockheed

CONCLUSIONS

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The environment of space provides a unique dimension for the study of human, animal, and plant physiology. This will surely result in additional knowledge leading to health and other benefits. A space station life sciences research facility is a mandatory step to obtain the answers required for future activities such as interplanetary exploration. One of the more significant research areas to be explored in this respect is defining man's capability in space. Life sciences clearly is one of the justifications for manned activities in space.





LMSC-D889718

## CONCLUSIONS

- SPACE PROVIDES A NEW DIMENSION FOR LIFE SCIENCES RESEARCH
- SPACE STATION IS A MANDATORY STEP TO OBTAIN LIFE SCIENCES ANSWERS FOR FUTURE
- LIFE SCIENCES PROVIDES SIGNIFICANT JUSTIFICATION FOR MANNED ACTIVITIES IN SPACE

 Lockheed



## **TASK 1—MISSION REQUIREMENTS**

- 1.1 USER ALIGNMENT PLAN**
- 1.2 SCIENCE AND APPLICATIONS**
  - PHYSICAL SCIENCES
  - LIFE SCIENCES
- 1.3 COMMERCIAL**
- 1.4 U.S. NATIONAL SECURITY**
- 1.5 SPACE OPERATIONS**
- 1.6 REQUIREMENTS FROM USER NEEDS**
- 1.7 FOREIGN CONTACTS**

The Lockheed logo features a stylized 'W' or arrowhead shape followed by the word "Lockheed" in a bold, italicized, sans-serif font.

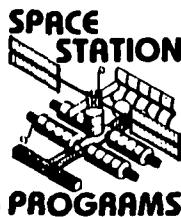
EVOLUTIONARY STRATEGIES AND PROGRAM OPTIONS

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Commercial missions have important implications for space station program planning. The task of the system designer is not to specify a definite final design for the space station, but to establish rules which ensure that the various modules or sub-assemblies will work together effectively as a system, while permitting the maximum flexibility in the design of the individual units. In budget planning, the objective is not necessarily to complete the space station (however, that is defined) at minimum cost, but to make the commercial missions economically attractive at the earliest possible date. The goal is to obtain a positive cash-flow with minimum initial investment of money and time, and then to maximize the return on investment. To stimulate development of commercial missions, the objective of the space station studies should not be to pick winners amongst potential technologies, but to create the climate for innovation and entrepreneurial success.

The term "space station" often connotes a single, dedicated structure in Earth orbit, but in practice the facility is likely to be an assemblage of loosely coupled or free-flying structures or an "Industrial Park." The space station development program can have clearly-defined milestones, but there will be no specific event signifying completion of the facility. If the project is successful, the station will grow and change for an indefinite period, in ways that are not now predictable: it might remain largely a research facility, it might form the nucleus for industrial projects in Earth orbit, and it might become the staging base for the exploitation of extraterrestrial material and energy resources.

Commercial opportunities in the space station do not consist exclusively of "space applications" i.e., the provision of goods and services for other users of space (commercial or government). For example, a commercial orbital transfer service could be set up to ferry payloads from the space station in low Earth orbit to locations in geosynchronous orbit. Some utility services (power, life support, etc.) aboard the space station could also be developed as commercial ventures.



## COMMERCIAL MISSIONS - AN EVOLUTIONARY STRATEGY

- IMPLICATIONS OF COMMERCIAL MISSIONS FOR SPACE STATION PROGRAM PLANNING
- THE SPACE STATION AS AN "INDUSTRIAL PARK"
- COMMERCIAL OPPORTUNITIES FOR PROVISION OF GOODS AND SERVICES FOR USE ON EARTH AND FOR OTHER USERS OF SPACE
- STRATEGY COMPONENTS:
  - PRIVATE SECTOR INVOLVEMENT
  - DESIGN FEATURES
  - COORDINATION REQUIREMENTS

REASONS FOR COMMERCIAL RESEARCH IN SPACE

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The moment has been reached that continuing research on earth to guess how space experiments will come out, is on a diminishing return curve. It is time that a concerted effort is launched to find out what industry needs, what can be done in space, and then perform the experiments to prove they can do what we expect. With this information in hand industry will be more willing to invest and build pilot plants.





## REASONS FOR COMMERCIAL RESEARCH IN SPACE

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- UNCOUNTED POSSIBLE BENEFITS COULD BE REALIZED
- FEASIBILITY OF SPACE EXPLOITATION HAS TO BE VERIFIED
- MAN'S QUEST FOR PROFITS AND CONQUERING FRONTIERS
- NEW INDUSTRY AND SPIN-OFFS WILL IMPROVE ECONOMY AND REDUCE LABOR SURPLUS
- BETTER UNDERSTANDING OF PROCESSES AND THUS POSSIBILITY FOR IMPROVEMENTS ON EARTH

BENEFITS OF SPACE COMMERCIALIZATION

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With the tremendous growth of the satellite communication industry still going strong, proof of space business opportunity is there. Spin-offs from these space ventures require no proof. Starting with early space exploration a large number of spin-offs have become profitable ventures here on earth.

Space is probably the last remaining frontier and it will certainly yield its secrets as more time is spent in that environment. Commercial opportunities will show themselves in space as the obvious ones already have.





## BENEFITS OF SPACE COMMERCIALIZATION

- COMMUNICATION SATELLITES ALREADY CREATED A NEW INDUSTRY AND SPIN-OFFS
- THE LAST REMAINING FRONTIER-WILL CREATE BUSINESS OPPORTUNITIES
  - REMOTE SENSING (GROWTH)
  - MATERIALS PROCESSING (START)
  - UTILITY SERVICES (LONG TERM)

WHY MANNED SPACE STATION-BASED RESEARCH

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With the opening up of a new frontier, Space based research will become an important force in the drive to total space exploitation. As the results of space research start to come in, more areas for research will be opened, eventually resulting in commercial applications.

Having a space station would greatly enhance those research programs that require long time on orbit. With man available in space an experiment or research project could have a lower starting cost because of a lesser amount of automation. Man in space can fix problems in operation, data acquisition, and can also change the direction of an experiment without going back to earth.





## WHY MANNED SPACE STATION-BASED RESEARCH

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- INITIAL RESEARCH WILL BE ENHANCED BY MAN'S PRESENCE
- ALLOWS EXTENDED TIME FOR RESEARCH AS COMPARED TO SHUTTLE
- AFFORDS A LOT MORE SPACE AND MASS PER EXPERIMENT FOR MORE EXPERIMENTS THAN SHUTTLE
- PILOT PLANT FREE-FLYERS HAVE MANNED INSPECTION CAPABILITY CLOSE BY WITH A SPACE STATION
- COULD SAVE RESEARCH AND DEVELOPMENT TIME BY SOLUTIONS ON ORBIT
- MORE COST EFFECTIVE FOR LONG DURATION EXPERIMENTS

### USER SURVEY APPROACH

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During the proposal period it was decided not to conduct a letter/questionnaire campaign because of its extremely low rate of return.

Seminars for selected groups of people were thought to be a more efficient approach. This to be augmented by as many personal telephone contacts followed by multiple visits as would fit time and budget. Presentations to special interest groups, such as the Air Force Materials Lab and Metal Powder Association were another method of reaching large numbers of industries.





## USER SURVEY APPROACH

- SEMINARS WITH FOLLOW-ON VISITS
- PERSONAL TELEPHONE CONTACTS WITH MULTIPLE FOLLOW-ON VISITS
- PRESENTATIONS TO SPECIAL INTEREST GROUPS
  - METAL POWDER ASSOCIATION
  - AIR FORCE MATERIALS LAB

COMMERCIAL USERS SEMINARS

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With these seminars Arthur D. Little/Lockheed planned to contact high level management of carefully selected industries, and through these contacts create a better understanding for space station and its capabilities.

The high technology possibilities and the need to participate in this space venture were highlighted throughout the seminar presentations.





## COMMERCIAL USER'S SEMINARS

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BOSTON SEMINAR 10 NOVEMBER 1982  
SAN JOSE SEMINAR 27 JANUARY 1983

A. PURPOSE:

- INTERACTION NECESSARY TO GAIN COMMERCIAL HIGH LEVEL MANAGEMENT INVOLVEMENT
- IDENTIFY COMMERCIAL INTEREST
- SOLICIT AND DEMONSTRATE NEED FOR USER INTERACTION, SUPPORT AND HIGH TECHNOLOGY INFUSION

B. EXECUTIVES OF 220 COMMERCIAL ENTERPRISES WERE INVITED TO BOSTON, MASS., AND SAN JOSE, CA.

- 48 ATTENDED FROM BROAD SPECTRUM OF NON-AEROSPACE INDUSTRIES
- A STRONG INTEREST IN SPACE WAS SHOWN
- FOLLOW-UP VISITS WERE MADE ON AN INDIVIDUAL COMPANY BASIS



BOSTON SEMINAR AGENDA

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The Boston seminar on 10 November 1982 was the first of two seminars held during this study contract period. A reception on the evening before the seminar gave all the attendees an excellent opportunity to talk space station with the Arthur D. Little and Lockheed staff.

The agenda is self explanatory. The technical presentations were given by the Arthur D. Little staff and consultants. Possibilities and capabilities of work in space were presented to a level to instill enough interest in the attendees to request follow-up visits.





## BOSTON SEMINAR AGENDA

### COMMERCIALIZING SPACE: THE BARRIERS AND OPPORTUNITIES

Tuesday Evening, November 9

6:00-8:00 Welcoming Reception — The Colonnade West

Wednesday, November 10 Meeting — The Embassy Suite

8:30	Coffee	Mr. William F. Wright Vice President, Space Systems Division Lockheed Missiles and Space Company, Inc.
9:00	Opening Remarks .....	Dr. Peter Glaser Meeting Chairman, Vice President, Arthur D. Little, Inc.
	Overview .....	Mr. John D. Hodge, Director, Space Station Task Force, NASA
	Space Station — Attributes and Needs .....	Dr. Kevin Forsberg, Manager, Space Station Program, Lockheed Missiles and Space Company, Inc.
	User Involvement in Space Station Development .....	Dr. Gerald P. Carr Senior Consultant Applied Research, Inc.
	Working in Space .....	Dr. Peter Glaser
	Rationale for Commercial Activities in Space .....	
10:45	Break	
11:00	Concurrent Seminars Led by Arthur D. Little Technical Staff:	
	• Utility Services .....	Dr. Philip K. Chapman Senior Professional Staff
	• Materials Processing .....	Dr. Arthur A. Fowle, Consultant to Arthur D. Little, Inc.
	• Telecommunications .....	Mr. Robert S. Gordon Senior Professional Staff
	• Medical Services .....	Dr. Jack Kasten Vice President
12:00	Luncheon	
1:45	Panel and General Discussion .....	Dr. Thomas O. Paine, Moderator Chairman, Thomas Paine Associates
	• Business factors and highlights including NASA support of commercial space operations	
	• NASA handling of proprietary data	
	• Open discussion	
3:45	Summation .....	Dr. Peter Glaser
4:00	Adjournment	

Members of Lockheed/Arthur D. Little Study Team will be available for informal discussion.

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Arthur D. Little, Inc.



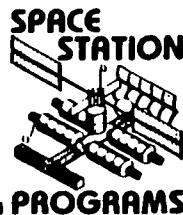
BOSTON SEMINAR ATTENDEES

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Of about 120 invitees, 28 accepted the invitation and attended the seminar. The attendance list shows the companies that were represented at the seminar.

A questionnaire was passed by the attendees, it resulted in 15 requests of follow-on visits.





## BOSTON SEMINAR ATTENDEES

### COMMERCIALIZING SPACE: THE BARRIERS AND OPPORTUNITIES

Allied Corporation	Mr. Samuel Levinson
Alpha Industries	Mr. James C. Korcuba
Aluminum Company of America	Mr. G.K. Turnbull
AMP Incorporated	Mr. George Cvijanovich
Bacti-Consult Assoc.	Dr. Lorraine S. Gall
Baxter Travenol	Dr. John A. Thomas
Becton Dickinson	Mr. Donald S. Hetzel
Bell Labs	Mr. Douglas Reudink
Brigham & Women's Hospital	Mr. Herbert Sherman
Corning Glass Works	Mr. Roger G. Ackerman
General Electric Company	Mr. Richard W. Hesselbacher
GTE Laboratories	Dr. Peter Cukor
GTE Laboratories	Dr. William McNeil
GTE Products Group	Mr. Charles P. Smith
GTE Satellite Corporation	Mr. Glen Allen
Hercules, Inc.	Mr. Perry S. Bruno
Honeywell Incorporated	Dr. Paul Kruse
Itek Corporation	Mr. Frederick J. Gilligan
Keystone Custodian Funds	Mr. Don Keller
Lahey Clinic	Mr. William A. Curby
Litton Industries	Dr. Robert M. Salter
Mobil Research & Development Corporation	Mr. J.J. Wise
New England Medical Center	Mr. Frank G. Stout
Norton Company	Mr. T.L. Loucks
Rockwell International	Mr. Earl G. Cole
Space Transportation Company	Mr. Klaus Heiss
United Technologies Corporation	Dr. Robert J. Hermann



SAN JOSE SEMINAR AGENDA

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The San Jose seminar on 27 January 1983 was the second and last seminar for this contract. The format of this seminar was similar to that one held in Boston on 10 November 1982.

Presentations covering the same subjects as in Boston were presented.

The invitations for this seminar were concentrated in the western part of the country, thereby cutting down on travel for the attendees.

At least 10 invitees could not attend because of board meetings that are normally planned for this time period. For future use dates for these type of gatherings should be chosen away from around the year end and beginning.





## SAN JOSE SEMINAR AGENDA

### COMMERCIALIZING SPACE: THE BARRIERS AND OPPORTUNITIES

**Wednesday Evening, January 26**

6:00-8:00 Welcoming Reception — Monterey Room

**Thursday, January 27 Meeting — San Juan-San Carlos Room**

8:30	Coffee	Mr. William F. Wright Vice President, Space Systems Division Lockheed Missiles and Space Company, Inc.
9:00	Opening Remarks .....	Dr. Peter E. Glaser Meeting Chairman, Vice President, Arthur D. Little, Inc.
	Overview .....	Mr. E. Lee Tilton, III, Chairman, Space Station Task Force, NASA
	Space Station — Attributes and Needs .....	Dr. Kevin Forsberg, Manager, Space Station Program, Lockheed Missiles and Space Company, Inc.
	User Involvement in Space Station Development .....	Dr. Gerald P. Carr Senior Consultant Applied Research, Inc.
	Working in Space .....	Dr. Peter Glaser
	Rationale for Commercial Activities in Space .....	
10:45	Break	
11:00	Concurrent Seminars Led by Arthur D. Little Technical Staff:	
	• Utility Services .....	Dr. Philip K. Chapman Senior Professional Staff
	• Materials Processing .....	Dr. Peter E. Glaser
	• Telecommunications .....	Ms. Vonna K. Deulen Senior Professional Staff
	• Medical Services .....	Mr. Thomas W. Chapman Senior Professional Staff
12:00	Luncheon	
1:45	Panel and General Discussion .....	Dr. Peter E. Glaser
	• Business factors and highlights including NASA support of commercial space operations	
	• NASA handling of proprietary data	
	• Open discussion	
4:00	Adjournment	

*Members of Lockheed/Arthur D. Little Study Team will be available for informal discussion.*

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SAN JOSE SEMINAR ATTENDEES

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Of about 100 invitees, 22 accepted the invitation and attended the seminar. The attendance list shows the companies that were represented at the seminar.

For this seminar we invited some of the young mavericks in the commercial space business, they provided a little spice to the discussions.

Questionnaires returned after the seminar resulted in 11 requests for follow-on visits.





## SAN JOSE SEMINAR ATTENDEES

### COMMERCIALIZING SPACE: THE BARRIERS AND OPPORTUNITIES

Bank America Corp.	Mr. Alan D. Rogers
Bechtel, Inc.	Mr. Harold B. Forsen
Bechtel, Inc.	Mr. George Wang
ECON	Mr. Jon Graham
ECON	Mr. Charles Hopkins
ECON	Mr. John Skratt
Fluor Eng. & Construction, Inc.	Mr. Bill Breen
GTS	Mr. Sam Dauncey
Kaiser Aluminum & Chemical Corp.	Mr. Dana Squire
Micom Systems, Inc.	Mr. James Walker
NASA-Ames	Mr. Richard P. Johnson
Opinion Research Corp.	Mr. Irwin Miller
Pacific American Launch Systems	Mr. Gary Hudson
Planning Group	Mr. Eugene Grigsby
Raychem Corp.	Mr. Tai Cheng
Raychem Corp.	Mr. Bruce McKinley
Rockwell International Corp.	Mr. George Merrick
SAI	Mr. Peter Vajk
SCI Systems, Inc.	Mr. Frank J. Gaude
Southern Pacific	Mr. John McGee
SRI	Mr. Jim Wilhelm
Standard Oil Co. (Indiana)	Mr. Sumner L. Nelson
Syntex Corp.	Mr. Cliff Mahler
Systems Development Corp.	Mr. Robert Salkeld
Terra-Mar	Mr. Don C. Walklet
Teledyne, Inc.	Mr. Bob Noblitt
Consultant	Mr. Mort Raphael

USER SURVEY CONTACT STATISTICS

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Various contact approaches were used to attract the commercial community to the space station. The statistics show that with the seminar more people were reached with an initial invitation but the return (efficiency) was only 23%.

By making direct telephone contacts, although more difficult than getting a letter to a high level officer, the yield improved incredibly. From these contacts came invitations to a trade association officers meeting in Florida. They were in turn interested enough to invite us to set up an Space Station information booth at the Metal Powder Industries Federation (MPIF) trade fair (1-4 May 83).

These surveys should be continued and expanded to include flight data exchange, and eventually specific experiments could be performed for the industries contacted. This growth process has to proceed any thought of commercialization.





## USER SURVEY CONTACT STATISTICS

METHOD OF CONTACT	INVITATIONS	ATTENDEES	YIELD
SEMINAR	220	50	23%
FOLLOW-ON VISITS		26	
TELEPHONE CONTACTS	50	45	90%
FOLLOW-ON VISITS		35	
PRESENTATION BY INVITATION (MPIF) FOLLOW-ON REQUEST TO EXHIBIT SPACE STATION AT TRADE FAIR TELEPHONE ARRANGEMENT FOR EXHIBIT AT TRADE SHOW (ERA)*		12 5,000	

NOTE: COMPLETE LISTING OF CONTACTS PRESENTED IN ATTACHMENT 2

\*ELECTRONICS REPRESENTATIVES ASSOCIATION

#### CONCLUSION ON COMMERCIAL CONTACTS

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Contacts made for the seminar yielded a lower percentage of attendance than a direct telephone call or letter. The direct telephone and letter approach does cost more time for the person making the contacts, but the yield is high.

In general a lot of interest for space work was instilled in the people contacted. Surprisingly the total knowledge available about space in general and NASA in specific in the commercial areas is rather minimal. More information needs to be relayed to a broader base of industries.

Most people contacted were willing to look into the possibilities for them in space. The problem was that many did not know how and where to start, which is a sign of not knowing what space can do for them.





## CONCLUSION ON COMMERCIAL CONTACTS

- APPRECIABLE INTEREST WAS EXHIBITED BY MAJORITY OF CONTACTS
- AGREEMENT THAT THE USA MUST BE FIRST IN HIGH TECHNOLOGY TO WITHSTAND FOREIGN COMPETITION
- REALIZATION OF THE NEED TO EXPLORE THE PROFITABILITY OF SPACE EXPLOITATION
- NUMEROUS QUESTIONS ON HOW SPACE WOULD IMPROVE PRESENT PROCESSES
- REQUESTS TO SHOW IMPROVEMENT POSSIBLE - "SHOW ME A SAMPLE"
- SMALL NUMBER HAVE MONEY AVAILABLE HOWEVER, THEY WANT A 5-6 YEAR RETURN
- MOST WANT TO BE KEPT INFORMED JUST IN CASE SOMETHING MAY TURN UP
- ELECTRONICS AND METAL PROCESSING ARE PROBABLY ABOUT 5 YEARS OFF
- PHARMACEUTICALS LOOK PROMISING FOR NEXT 3 YEARS MAINLY BECAUSE OF ELECTROPHORESIS
- COMMUNICATIONS WILL CONTINUE TO GROW, HOW MUCH SPACE STATION WILL HELP IS STILL A QUESTION

## POTENTIAL BENEFITS OF COMMERCIAL ACTIVITIES (1)

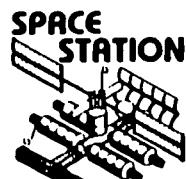
Telecommunications

The advancement of telecommunications will require low launch, assembly, and deployment costs. Interest is growing in the deployment of multi-mission satellites with a mass in the 5000kg range, and platforms with higher power output and onboard processing/switching capabilities. Lower user costs could be achieved by extending satellite life with on-orbit maintenance and repair. The space station could be a control center for satellite transmission, a relay and switching network, and the base for the assembly of platforms for multi-purpose system functions leading to orbital arc and spectrum conservation.

The space station could be used for evaluating new technologies, including satellite system networks for distributed and centralized architectures; multibeam antennas up to 100 meters in diameter; satellite relays; onboard processing and switching capabilities for microwave links, laser links, and modulators and switches; propulsion systems for transfer from low-Earth to geosynchronous orbit for assembly and deployment; control and stationkeeping means to achieve pointing of 0.2 degree beams; and electromagnetic wave propagation for the development of new spectral windows.

The space station represents "waterfront property" because a great value is attached to the desirable orbit positions which are limited in number. The space station could be an integral part of business planning strategies for organizations in the telecommunications field. Such a facility cannot belong to any single industrial organization because the magnitude of the investment would be difficult to justify. Participation in space station activities by industrial organizations active in telecommunications will insure that these companies can expand their commercial activities.





## POTENTIAL BENEFITS OF COMMERCIAL ACTIVITIES (1)

- TELECOMMUNICATIONS

 Lockheed

## POTENTIAL BENEFITS OF COMMERCIAL ACTIVITIES (2)

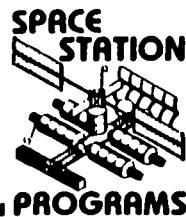
Materials Processing in Space

The scientific benefits of materials processing in space (MPS) which include: reducing buoyancy-driven natural convection, containerless processing, reducing gravity-induced separation of mixtures of materials with different densities, using containment structures that cannot survive on Earth, investigating molecular-level forces in microscopic systems, and testing experimentally the assumptions necessary in theoretical model systems with inherent complicated patterns of fluid density variations are increasingly accepted.

The commercial benefits, of MPS have to be demonstrated in future shuttle experiments to guide such activities in a space station. These benefits are projected to include: advances in the science and technology of materials processing; the demonstration of products with unique and valuable properties as a spur to the development of terrestrial alternative production methods; and the production of unique materials and products that could lead to a future space-based materials processing industry. At present, the most promising commercial applications of MPS include pharmaceuticals, electronic materials, glasses, and metal alloys and composites.

The most likely role for a space station in MPS is as a national laboratory for R&D. The space station is the only planned opportunity for U.S. industry to demonstrate MPS potential for commercial production, and to close the information gap between the U.S. and the USSR in MPS.





## POTENTIAL BENEFITS OF COMMERCIAL ACTIVITIES (2)

- MATERIALS PROCESSING

## POTENTIAL BENEFITS OF COMMERCIAL ACTIVITIES (3)

Utility Services

Incentives for industry participation in commercial activities could be provided by utility services supplied to space station users. If NASA, or an appropriate federal agency created for this purpose, would provide long-term guarantees and service contracts, companies might be interested in providing facilities and services charged to the users in ways analogous to similar services provided in terrestrial industrial facilities. Examples of such utility services are power supplies; housekeeping and life support including equipment, consumables, and waste management; habitability features, including crew accommodations, recreational facilities and food preparation and service; medical and health care; personnel services including crew selection and training and contract personnel; rent or sale of standard modules that may be attached to a space station structures, and free-flying carriers; engineering, consulting, design, and fabrication; temperature control of experiments and processing systems; telecommunications and data handling; operation of earth-to-orbit and orbital transfer, manned or unmanned, transportation systems and on-orbit refueling facilities for such systems.

NASA's and other federal agencies function would be to assure that the facilities and services provided to a space station meet the user's needs, that they are well integrated with the space station requirements, and that they meet necessary performance and safety criteria. The return on industry investments to provide commercial facilities and services would be negotiated between participants in space station commercial activities in a competitive environment, with industry taking the lead to develop and provide the necessary facilities and services on a business basis. These commercial activities could be planned from a modest and embryonic start to encompass future major investment in space industrialization regulated by both U.S. and international space commerce agencies.





## POTENTIAL BENEFITS OF COMMERCIAL ACTIVITIES (3)

- UTILITY SERVICES

## MATERIAL PROCESSING IN SPACE (1)

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Very little materials processing has been done in space in the past. Data in this area has to come from experiments planned for flight in the coming years. Specific industries should be researched and experiments with their specialized requirements in mind should be conducted. The positive results of these experiments will draw the commercial interest that has been lacking so far.

Industrial capital investors want to know what their return will be and when, against what probability of success. This means that what we want to do in space has to be well defined when presenting it.





## MATERIAL PROCESSING IN SPACE (1)

### AMERICAN ACTIVITY

- NASA COMMITMENT FOR MPS EFFORT HAS NOT INCREASED SIGNIFICANTLY (ABOUT \$20M)
- EXPERIMENTERS MAINLY DRAWN FROM NASA, UNIVERSITIES, RESEARCH INSTITUTES, AND AEROSPACE COMPANIES
- TRUE COMMERCIAL PARTICIPATION NOTABLE BY ITS ABSENCE (SAME IN OTHER COUNTRIES)

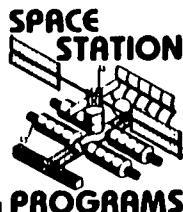
NOTE: EXCEPTION - MDAC/JOHNSON & JOHNSON

- NASA STUDY CONTRACTS DESIGNED TO INVOLVE AND DRAW IN THE COMMERCIAL INTEREST
- STATION ARCHITECTURE AND COSTING ACTIVITIES IN PROGRESS

## MATERIAL PROCESSING IN SPACE (2)

The activity in Europe is based on the use of Shuttle for their space material processing effort. In some technology areas the fact that a number of the "sciences" were called upon to study and plan a space experiment, already has borne fruit for processes here on earth. This proves that a carefully planned operation is required to get industry and the sciences together to find ways to use space but also to do things better here and now.





## MATERIAL PROCESSING IN SPACE (2)

### EUROPEAN ACTIVITY

- EFFORT IS PARTIALLY DRIVEN BY ESA BUT ALSO ON A NATIONAL BASIS
- ROCKET FLIGHTS STILL PROMINENT IN RESEARCH EFFORT
- NUMEROUS EXPERIMENTS PLANNED WITH SHUTTLE - SPACE LAB, SPAS, EURECA
- SPACE STATION STUDIES IN PROGRESS
- BUDGETARY AND POLITICAL PRESSURES MAKE FOR CAREFUL PLANNING

MATERIAL PROCESSING IN SPACE (3)

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The Japanese are presently spending a rather small amount of money in space research specifically in the area of material processing in space. Their forte lies in the area of electronics and robotics and here they are putting forth a sizable effort.

Their efforts in material processing although low level, may have borne them some fruit namely a hardness in metal that cannot today be explained. However, it is these type of happenings that make a new frontier exciting.





## MATERIAL PROCESSING IN SPACE (3)

### JAPANESE ACTIVITY

- DEVELOPMENT AND EFFORT PROCEEDING TO BUDGET AND SCHEDULE
- MPS EFFORT IS NOT PROMINENT IN JAPANESE PLANNING - COMMUNICATIONS AND ELECTRONIC RELATED ACTIVITIES ARE
- PERFORMANCE OF SOUNDING ROCKETS (TT-500A) FOR EXPERIMENTS
- FLIGHTS PLANNED ON SHUTTLE (JAPAN T&T CORP)
- JAPAN SO FAR UNWILLING TO TAKE THE BIG (EXPENSIVE) SPACE LEAP
- CONCENTRATE ON PUTTING HUMAN'S INTELLIGENCE INTO A MACHINE FOR SPACE EXPLOITATION (ROBOTICS)

## MATERIAL PROCESSING IN SPACE (4)

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The Russians have to date expended the largest effort in space station related work and probably have performed more experiments in areas ranging from human behavior to material processing. Of course not having complete information about all they did, leaves many unanswered questions. Apparently the opinions that existed earlier about the good work they have done are now changing to the negative direction.

All in all, they have a station and we have not. Hopefully, this will change in the not too distant future.





## MATERIAL PROCESSING IN SPACE (4)

### RUSSIAN ACTIVITY

- CONDUCTING MANY EXPERIMENTS IN SALYUT 6/SALYUT 7 SPACE STATIONS
- ALLOY AND CRYSTAL EXPERIMENTS - REFERENCE TO CADMIUM-MERCURY-TELLURIDE
- LACKS COMMERCIAL COMPONENT
- APPARENTLY THEY SPEND MORE ON RESEARCH THAN USA
- POSITIVE OPINIONS OF IMPRESSIVE WORK IN EARLY TIMES NOW SEEN TO SHIFT TO DOUBTS
- MORE AGGRESSIVE APPEARING SPACE POLICY THAN USA
- EMPHASIS ON NEW ORBITAL STATIONS AS A STEP TO SPACE LASERS

SEMINAR PRESENTATION

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A shortened version of the Dr. Glaser seminar presentation is given in the following charts. The uncut version of these charts was presented at the mid-term review by Peter Glaser of Arthur D. Little, Inc.





## SEMINAR PRESENTATION

- EXCERPTS OF PETER GLASER PRESENTATION GIVEN AT THE BOSTON AND SAN JOSE SEMINARS

CORE TECHNOLOGY AND SPACE APPLICATIONS

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Successful development of commercial ventures in space will be built on a solid base of core technology. The core technology can be compared to a tree. The roots draw on many facets of our society. Certainly our technological strength developed in this industrial society plays a key role in providing fundamental capabilities to develop new business ventures. But other aspects of our society are equally important including the legal framework, the development of public support, the utilization of our industrial resources as well as the human, material, and financial resources of the nation. Crucial in setting our direction in this challenging new era are federal policies for both domestic and foreign activities related to space, and our domestic federal policy towards utilization of expertise gained from the military for commercial purposes.

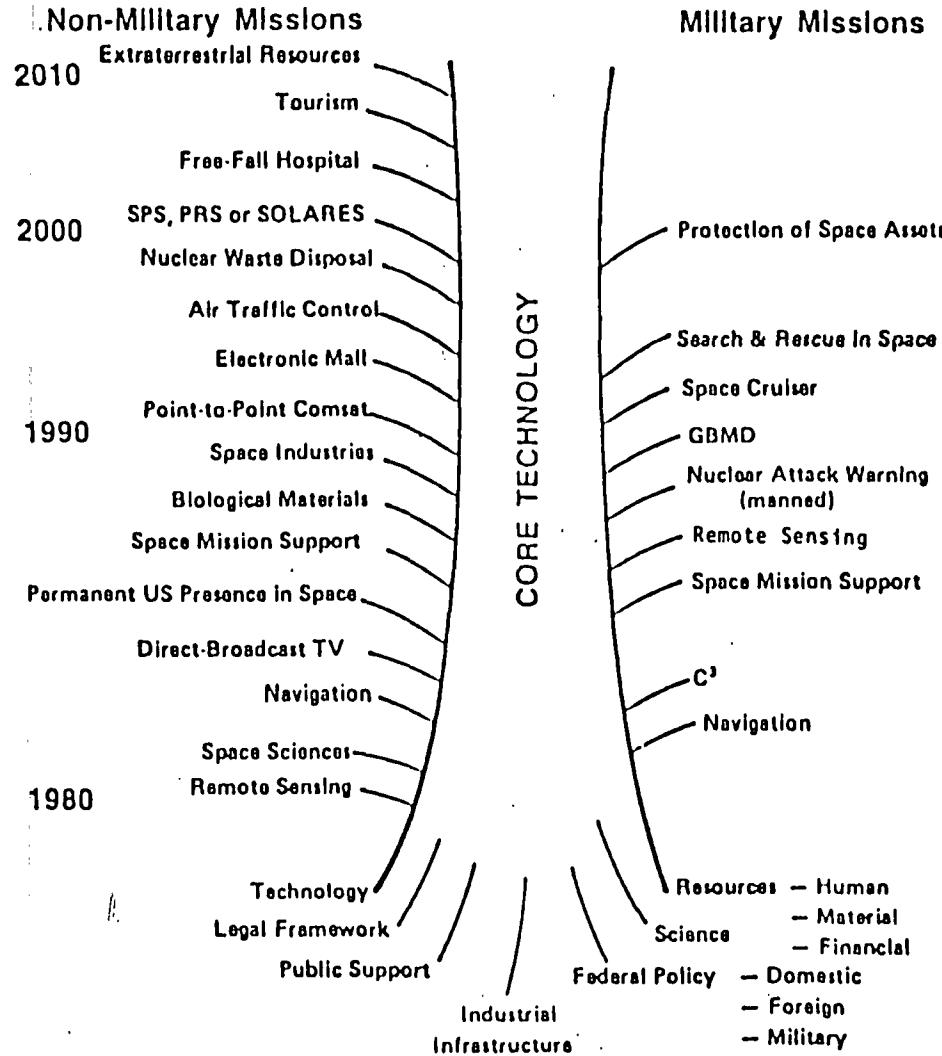
The current activities in space can be broken into two primary categories of nonmilitary missions and military missions. Both of these user communities draw on the same core technology as indicated on the facing page and the successful evolution of a strong US commercial involvement will depend upon the centerism between the differnt branches of this tree of core technology. It is not a one-way street since the military will certainly benefit from the improvements developed by the commercial world for space applications.





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## CORE TECHNOLOGY AND SPACE APPLICATIONS



ORIGINAL PAGE IS  
OF POOR QUALITY

 Lockheed

THE US ECONOMY IN TRANSITION

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The United States is a technologically oriented nation and our strength lies in high technology industries. During the past 35 years the United States has been a dominant figure in world economy and certainly a dominant user of space resources. During the past decade conditions have been changing however, and we now see the emergences of an interdependent global economy. We are no longer the leader in all areas, but now find ourselves only one of a group of economically strong countries, all of whom are interested in exploiting space. The United States is now the tenth in gross national product per capita.

In a global economy it is no longer clear what country will produce what items. The Japanese, for instance, dominated the shipping industry with their advanced manufacturing methods and the development of super-tankers. Today, however, countries such as Spain and Brazil are taking the lead in these areas. As the underdeveloped countries become more industrialized they become an effective competitor in the world of manufactured products. Because of lower labor rates they are very competitive and the quality of their products is very high. This trend towards moving industrialized activities away from Europe and the United States towards the third world will increase in the coming decades because of the significant population growth and increase in the work force currently being projected.





## THE U.S. ECONOMY IN TRANSITION

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- EMERGENCY OF INTERDEPENDENT GLOBAL ECONOMY
- U.S. ONLY ONE OF A GROWING NUMBER OF ECONOMICALLY STRONG COUNTRIES
- U.S. IS 10TH IN GNP PER CAPITA
- IN A GLOBAL ECONOMY, IT IS NO LONGER CLEAR WHICH COUNTRY WILL PRODUCE WHAT
- GROWTH OF THIRD WORLD COUNTRIES AS SOURCE OF MANUFACTURED PRODUCTS
- INCREASES IN WORK FORCE BY YEAR 2000
  - LATIN AMERICA AND AFRICA 80%
  - ASIA AND PACIFIC 55%
  - U.S. 10%

US EXPORTS

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Another measure of the change in the world economy is the decline of the US share of world exports and the relative growth of that experience by other sophisticated industrial societies. Clearly the United States no longer dominates the world market for manufactured goods. The largest dollar volume item in our export list is agricultural products. Note that the very high technology area of aerospace products account for 25% of our total export activity.





## U.S. EXPORTS

SINCE 1960, U.S. SHARE OF WORLD EXPORTS DROPPED FROM 16% TO 11%

EXPORTS AS % OF GNP

U.S.	-	7%
JAPAN	-	10%
WEST GERMANY	-	20%

SIX AEROSPACE CORPORATIONS ACCOUNT FOR 25% OF TOTAL OF \$32 BILLION  
EXPORTED BY 50 COMPANIES



## DUAL ECONOMY

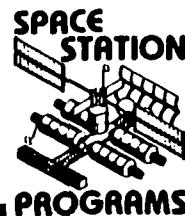
The United States has during the past 50 years evolved into a high technology society, and we have dominated those markets in which high technology played a key role. The production of automobiles, manufacturer of steel, and processing of textiles are typical examples of high technology of the earlier part of this century. As discussed earlier the third world countries have now emerged as strong competitors in many of these areas and what was high technology early in this century has become routine technology available to all. Because of the lower labor rates and the attention to quality in their products, these emerging countries have become effective competitors and have significantly encroached on a market formerly dominated by the US.

It is useful to consider the economy of the United States as being broken into two categories consisting of sun rise industries and sunset industries. The United States demonstrated leadership in the introduction of mass production in the automobile industry and during its sun rise period, the United States was a major source of innovation and technology. The automobile industry is now moving into a sunset phase in that many nations produce high quality vehicles that are very competitive in all respects to the US built equipment. The automobile industry in the United States uses the results of high technology activities in other areas, such as the development of automation and the use of robots on the assembly line. We are not, however, the innovators in this field and the lead has been taken by other countries. The same is true of many other industries such as shoe manufacuer, textiles, furniture, etc.

In the fields of electronics, computers, aerospace, and biotechnology, the United States is clearly one of the world leaders in innovation and in successful commercial application of the concepts of these areas.

A common threat that runs through these observations is that high technology areas represent areas of strength for the United States, and are areas where we can effectively compete in the world market. When the technology becomes mature and available on a routine basis, then a less industrialized nations can draw on their extensive labor base to become effective competitors. The future of this nation clearly rests on the development and exploitation of our strengths which lie heavily in the high technology areas. The United States must explore the new frontier of space vigorously or we will loose the initiative to other, equally well developed, industrial nations and thus loose out on the ability to capitalize on areas of our major capability.





## DUAL ECONOMY

PROGRAMS

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### SUNRISE INDUSTRIES:

ELECTRONICS  
SOFTWARE  
ROBOTICS  
AEROSPACE

COMPUTERS  
BIOTECHNOLOGY  
ALTERNATIVE ENERGY TECHNOLOGIES

### SUNSET INDUSTRIES:

SHOES  
TEXTILES  
FURNITURE

AUTOMOBILES  
STEEL  
CONSUMER ELECTRONICS

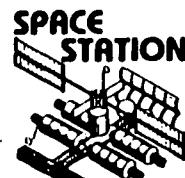


ANNUAL NUMBER OF PATENTS GRANTED SINCE 1965

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The pursuit of commercial ventures requiring high technology benefits the nation as well as the individual companies, since the exploration of new frontiers stimulates ideas that may have far reaching implications. A majority of this is found in the annual number of patents issued during the past two decades. Germany and Japan have emerged as dominant world figures and they have been vigorously pursuing any aspects of high technology. The United States has been stagnant in certain industries such as the automotive and steel, and this broad based commercial stagnation is reflected in the reduction in number of patents issued over this period. The strong technical innovation in certain portions of our society need to be stimulated even more vigorously and the pursuit of commercial opportunities in space is an exciting opportunity to do just that.





## ANNUAL NUMBER OF PATENTS GRANTED SINCE 1965

U.S.	- 20%
FRANCE	+ 130%
JAPAN	+ 900%

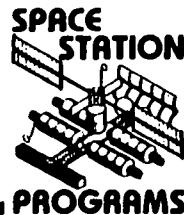


STRATEGIES FOR SPACE INDUSTRIALIZATION

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The development of commercial enterprise in space is a long term activity and requires a long range view and global outlook. Many countries are interested in exploring space and development of US commercial interests will require a national space policy which includes the foreign policy considerations for exploring international markets as well as developing cooperative ventures with other governments. New institutional structures will have to be established and the legal and regulatory framework developed to insure a sound legal basis for developing commercial activity in space.





## STRATEGIES FOR SPACE INDUSTRIALIZATION

- LONG-RANGE VIEW AND GLOBAL OUTLOOK
- INTEGRATION WITH NATIONAL SPACE POLICY PLANNING
- NATIONAL/INTERNATIONAL MARKETS
- INDUSTRY/GOVERNMENT COOPERATION
- INSTITUTIONAL STRUCTURES
- LEGAL AND REGULATORY FRAMEWORK
- INVESTMENT MECHANISM



## ORGANIZATIONS CONTRIBUTING TO SPACE INDUSTRIALIZATION

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As can be seen on the facing page many countries are becoming involved in space industrialization both the US and the European communities no longer hold a monopoly in this area.





## ORGANIZATIONS CONTRIBUTING TO SPACE INDUSTRIALIZATION

FORM. DATE	ORGANIZATION	COMPOSITION	ACTIVITIES
1980	• SPACE SERVICES	U.S. INVESTORS	MINUTEMAN LAUNCH
1980	• PALAPA	INDONESIA	PROPOSED COMMUNICATION
1981	• SPACE TRANSPORTATION CO.	U.S. INVESTORS	SHUTTLE LAUNCH (PENDING)
	• AFROSAT	AFRICAN NATIONS	PROPOSED COMMUNICATION
	• ASEAN	S.E. ASIA NATIONS	PROPOSED COMMUNICATION
1982	• ORBITAL SYSTEMS	U.S. INVESTORS	CENTAUR LAUNCH
1982	• INSAT II	INDIA	COMMUNICATIONS
1983	• ASTROTECH	U.S. INVESTORS	SATELLITE SERVICING
1984 ↓ 1986	• SPOT IMAGE	CNES (1/3) FRENCH INVESTORS	EARTH RESOURCES SATELLITES

THE MARKET

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Telecommunications revenues have grown at a significant rate during the past 30 years to a current level of 150 billion dollars world wide. This activity, which includes all forms of telecommunications (both ground and space based) is projected to increase by a factor of 7 by the end of the century. The space based portion of the satellite communications is currently 10 billion dollars per year and this will increase to over 70 billion per year by the end of the century. There are challenges to this growth, however, as evidenced by the recent interest in Japan and in the United States in using fiber optics to replace existing ground-based hard wire systems and microwave systems. The fiber optics offer sufficient potential that many anticipate they will be a strong competitor to space activities as well. In order to retain the lead in space based communications, it is essential that advances in technology over the past 20 years be incorporated in new generations of satellites systems and that these systems be made even more economical. Again a space station may play a key role in helping produce more cost effective systems for the future.





## THE MARKET

	1982 (\$ BILLION)	2000 (\$ BILLION)
TELECOMMUNICATIONS REVENUES WORLDWIDE TOTAL	150.	850.
SATELLITE COMMUNICATIONS REVENUES WORLDWIDE TOTAL	10.	77.
TELECOMMUNICATION CAPITAL EQUIPMENT TOTAL	50.	283.

DEMONSTRATED BENEFITS OF COMMERCIAL ACTIVITIES - 1982

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The telecommunications industry has developed a very profitable commercial use of space during the past two decades. The present annual market is approximately 10 billion dollars and this is expected to grow substantially (some estimates indicate a factor of 10) by the end of this century. Earth resources offer potential opportunities for commercial development but this area is still embryonic as a self sustaining commercial enterprise. Many companies have found land sat data to be extremely valuable however. The current government policy is to make this area totally self sustaining on a commercial basis by the later part of this decade.

Navigational information is presently available on a commercial basis and we now see the emergence of other countries as competitors providing this service. Vigorous exploitation of improved technology may allow the United States to remain in the forefront of this field since substantial improvements and capabilities have evolved over the past decade.





## DEMONSTRATED BENEFITS OF COMMERCIAL ACTIVITIES - 1982

- TELECOMMUNICATIONS

- 150 PARTICIPATING NATIONS
- 120 ORBITING SATELLITES
- \$10 BILLION PER YEAR MARKET
- 50,000 TRANSATLANTIC CIRCUITS
- DIRECT BROADCAST TV
- SEARCH AND RESCUE

- EARTH SCIENCES

- REMOTE SENSING
  - MINERAL RESOURCES
  - CROPS
  - POLLUTION MONITORING
- GEOLOGIC MAPPING
  - CARTOGRAPHY
  - HYDROLOGY
  - EARTHQUAKE PREDICTION

- NAVIGATION

- 50 FEET POSITION ACCURACY

- TECHNOLOGY TRANSFER

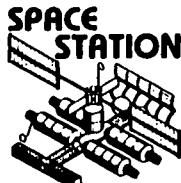
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PROJECTED BENEFITS OF COMMERCIAL ACTIVITIES IN SPACE

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During the coming decades there are 5 areas that offer opportunities for commercial development. The list on the facing page shows these in order of existing commercial activity (telecommunications), near term opportunities (remote sensing and materials processing) with some very speculative far term areas such as utility services and medical services suggested for development towards the end of the century. Further evolution of commercial activities can certainly benefit from the presence of a space station, particularly in the materials processing area since a long duration orbiting research facility will help identify the benefits of space based processing and help evolve pilot facilities which will demonstrate the commercial financial benefits from space based activities.





## PROJECTED BENEFITS OF COMMERCIAL ACTIVITIES IN SPACE

TELECOMMUNICATIONS

REMOTE SENSING

MATERIALS PROCESSING

- CRYSTAL GROWTH
- SOLIDIFICATION
- FLUID AND CHEMICAL PROCESSING
- CONTAINERLESS PROCESSING
- BIOLOGICAL MATERIALS SEPARATION
- BIOLOGICAL MATERIALS STORAGE

UTILITY SERVICES

MEDICAL SERVICES

 Lockheed

MATERIALS PROCESSING IN SPACE PROGRAM

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Many possibilities for processing in space exist as shown on the figure. But equally important is the research to be performed in space, results of which could lead to improvements of processes here on earth.

In theory we understand the phenomena of weightlessness but in the practical application we are lacking. Experiments have to be conducted in order to be able to chose those areas where a profitable production can be realized. We not only have to gain more knowledge in the absolute values of the space environment influences but also, what small perturbations will do to our research or processes.





## MATERIALS PROCESSING IN SPACE PROGRAM

### PROGRAMS

#### CURRENT AREAS OF RESEARCH

- CRYSTAL GROWTH AND SOLIDIFICATION
  - SOLID SOLUTION IR DETECTORS (HgCdTe, PbSnTe)
  - VAPOR GROWTH ( $HgI_3$ , ALLOY TYPE)
  - SOLUTION GROWTH (GROWTH ENVIRONMENT VS. MORPHOLOGY)
  - FLOAT ZONE (MARANGONI CONVECTION, RADIAL SEGREGATION, INTERFACIAL STABILITY)
- METALLURGICAL MATERIALS AND PROCESSES
  - IMMISCIBLE ALLOYS
  - MAGNETIC COMPOSITES
  - METALS FOAMS
  - HIGH GROWTH RATE SOLIDIFICATION
  - SOLIDIFICATION AT EXTREME UNDER-COOLING
- COMPOSITES
  - CASTING OF DISPERSION STRENGTHENED ALLOYS
  - SOLID ELECTROLYTES WITH DISPERSED ALUMINA
  - PARTICLE PUSHING BY SOLIDIFICATION INTERFACES
- GLASSES
  - GLASS FINING
  - LASER HOST GLASSES
  - OPTICAL GLASSES WITH UNIQUE PROPERTIES
  - METAL GLASSES
- CHEMICAL PROCESSES
  - MONODISPERSE LATEXES (POLYSTYRENE MICROSPHERES)
  - STABILITY OF FOAMS AND SUSPENSIONS
  - COLLOIDAL INTERACTIONS
  - HIGH TEMPERATURE PROPERTIES OF REACTIVE MATERIALS
  - DIFFUSION CONTROLLED SYNTHESIS
- SEPARATION SCIENCES
  - HIGH-VOLUME, HIGH-RESOLUTION ELECTROPHORESIS CELL SEPARATION
  - PROTEIN PURIFICATION BY CONTINUOUS FLOW ISOELECTRIC FOCUSING
- FLUID STUDIES
  - NON-BUOYANCY DRIVEN CONVECTIONS
  - WETTING AND SPREADING STUDIES
  - ROLE OF CONVECTION IN PROCESSES (ELECTRO-KINETIC, SEPARATION, ELECTROPLATING, CORROSION, ETC.)

SOURCE: NASA



COMMERCIALIZATION OF FUTURE ACTIVITIES IN SPACE

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A number of potential activities for commercial activities in space are presented. The timing for commercialization for most is probable in the coming decade, some of the presently less obvious possibilities could come at a later date. Although the list contains areas that seem highly improbable at present, we have still left these without giving them a lot of attention. One of these areas is medical services, which on present impulse should be withdrawn however, early withdrawal may not be prudent. Drugs and alloys may offer the best possibilities and should be vigorously pursued. Sensors are of course already in wide use but their use and sophistication will improve many fold during the next decade with long term space research.





## COMMERCIALIZATION OF FUTURE ACTIVITIES IN SPACE

TIMING FOR COMMERCIALIZATION	APPLICATION	INDUSTRY SECTOR	PARTICIPANTS
1985 - '95	DRUGS	PHARMACEUTICALS	RESEARCH EQUIP. VENDORS DRUG FIRMS PROCESS EQUIP. VENDORS
1985 - '95	ALLOYS	METALS	RESEARCH EQUIP. VENDORS
1985 - '95	SEMICONDUCTORS	ELECTRONICS	ELECTRONIC FIRMS EQUIPMENT VENDORS
1985 - '95	SENSORS	AEROSPACE	AEROSPACE FIRMS
1985 - '95	TELECOMM. PLATFORMS	COMMUNICATIONS	ELECTRONICS AEROSPACE EQUIPMENT VENDORS
1990 - 2000	MEDICAL SERVICES	HEALTH CARE	DOCTORS' ORGANIZATIONS HOSPITAL ORGANIZATIONS
1990 - 2000	FACILITY CONSTRUCTION	CONSTRUCTION	A&E FIRMS EQUIPMENT VENDORS
1985 - 2000	UTILITY SERVICES	MANUFACTURING	AEROSPACE EQUIPMENT VENDORS



CHALLENGES TO COMMERCIAL ACTIVITIES

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With the increasing attention given to space station and space exploitation, also on the international scene, it becomes more important to focus on the legal aspects for this new and lost frontier. Maybe a "Law of Space" similar to the "Law of the Seas" should be investigated. The third nations that are presently not in a military nor in an economic position to involve themselves with space, are stirring up a move of participation and even national ownership of space.

Some other issues will have to deal with in the very near future, they are the federal regulations that will control the total space operation.

On a more direct basis, the NASA interface with the commercial world has to be looked at. It may be too early to suggest that there be no direct interface but rather an aerospace company buffer between NASA and commercial enterprises.





## CHALLENGES TO COMMERCIAL ACTIVITIES

### LEGAL AND REGULATORY ISSUES

- OWNERSHIP OF EXTRATERRESTRIAL RESOURCES
- PROTECTION OF PROPRIETARY RIGHTS
- ANTITRUST CONFLICTS

### INTERFACES WITH FEDERAL GOVERNMENT

- REGULATIONS
- INTERFERENCE WITH OPERATIONS
- ACCOUNTABILITY
- LIABILITY
- COMMUNICATIONS

### POTENTIAL CONFLICT WITH DoD ACTIVITIES



CHALLENGES TO COMMERCIAL ACTIVITIES  
(CONTINUED)

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To continue with the challenges, we also have to commence with the development of supporting technologies. It is presently well understood that a system is required for transportation between space station components of personnel, equipment, and material.

For metallurgical processes we know that large amounts of power will be required.

With the orbit crowding of communication satellites we eventually will have to go to narrow beams which means larger antennas and more power, translating into the need for larger satellites. This would indicate the need for orbital staging area and methods of construction and checkout in space.

With the long lead times required for this type of effort a timely start will be beneficial.





## CHALLENGES TO COMMERCIAL ACTIVITIES (CONT)

### AVAILABILITY OF SUPPORTING TECHNOLOGIES

- SPACE TRANSPORTATION SYSTEM
- ORBITAL TRANSFER VEHICLES
- OPERATIONAL FACILITIES
- POWER SUPPLY

### LEAD TIMES TO DEVELOP COMMERCIAL OPERATIONS

- NASA/INDUSTRY JOINT VENTURES
- GOVERNMENT CONTROL OF ACCESS TO SPACE

INVESTMENT CRITERIA - GOVERNMENT

---

This areas falls in government "Space Policies and Regulations", where such things as tax incentives for space investment would be covered. If a favorable climate can be created for the investors, a much faster growth rate will result.

This is the type of information that potential space station users ask for. Special legislation is required to cover space exploitation for the benefit of our high technology competitiveness.





## INVESTMENT CRITERIA - GOVERNMENT

- PROMOTES THE PUBLIC INTEREST
- NATIONAL DEFENSE AND SECURITY ENHANCED
- FAVORABLE BENEFIT/COST RATIO AS DEFINED BY OMB

INVESTMENT CRITERIA - INDUSTRY

---

What the commercial community wants to hear when they are asked to invest in a commercial space venture, is listed on the figure.

Some of these issues listed require answers that cannot be given today and thus create a hesitance on the part of the potential user to involve himself. It has to be stressed that in the commercial area return on investment in a resonable time is one of the most important issues. The second one is to remain competitive.

It is within this sphere of industry investors that the government must create a business climate inducive to industry investment in space commercialization.





## INVESTMENT CRITERIA - INDUSTRY

- UNIQUE CONTRIBUTION OF SPACE ENVIRONMENT TO OPERATIONS
- POSITIVE NET CASH FLOW EXPECTED WITHIN REASONABLE TIME
- RELIABLE SUPPORTING TECHNOLOGIES AVAILABLE
- AFFORDABLE DEVELOPMENT COSTS
- EXISTING MARKETS OR NEW MARKETS OF PREDICTABLE SIZE AND CERTAINTY
- EXTENDED PRODUCT LIFE CYCLE
- SATISFACTORY PROPRIETARY POSITION
- ACCEPTABLE RISK - RETURN RELATIONSHIPS

SPACE STATION - A NATIONAL GOAL

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The words were there for all the world to hear. We are now ready for action. The world is looking for America to lead the free world quest into the space station era.





## SPACE STATION - A NATIONAL GOAL

COMMERCIAL ACTIVITIES IN A SPACE STATION ARE IN CONSONANCE WITH THE PRESIDENT'S AIM  
TO:

"KEEP AMERICA THE TECHNOLOGICAL LEADER OF THE WORLD NOW AND INTO THE 21ST  
CENTURY."

STATE OF THE UNION MESSAGE  
JANUARY 24, 1983

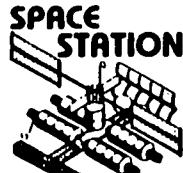
## CONCLUSIONS

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These conclusions about space commercialization were based on the contacts made with numerous industry representatives and the comments they made.

We also concluded that an important aspect of the user alignment plan is the personal contact approach where an open information exchange is possible.





## CONCLUSIONS

- COMMERCIAL FIRMS GENERALLY UNINFORMED ABOUT SPACE POSSIBILITIES AND ACCESS
- COMMERCIAL FIRMS VERY EAGER FOR COMPREHENSIVE INFORMATION (TECHNICAL AND STATE OF FOREIGN INVOLVEMENT AND PROGRESS)
- VERY FEW CONCRETE COMMERCIAL OPPORTUNITIES HAVE THUS FAR BEEN IDENTIFIED
- DATA BASE OF SPACE PHENOMENA INCOMPLETE
- MULTIPLE IN-DEPTH PERSONAL CONTACTS APPEAR MOST EFFECTIVE IN RELAYING DATA AND BUILDING CONFIDENCE

RECOMMENDATIONS

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The recommendations shown on the figure speak for themselves and are based on the trials and tribulations of the alignment plan activity.

The lack of solid information of direct interest to a potential user is hard to overcome. Therefore, we stress the point that obtaining this type of data/information is of the utmost importance.

Furthermore, it would be a waste to drop all contact with these people at this time. A method to continue these visits should be created. From past experience we know that after creating the interest, a long time gap will cause loss of momentum which can turn an enthusiast to a side-liner.





## RECOMMENDATIONS

- MORE ADEQUATE WRITTEN INFORMATION ESPECIALLY FOR BUSINESS COMMUNITY TO BE MADE AVAILABLE
- IN-DEPTH PERSONAL CONTACTS TO BE CONTINUED
- DATA BASE OF SPACE PHYSICAL PHENOMENA SHOULD BE EXPANDED BY NASA
- CONTACTS WITH INDUSTRIES VIA TRADE SHOWS AND OTHER LIKE MEANS TO BE FURTHER EXPLORED

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## **TASK 1—MISSION REQUIREMENTS**

- 1.1 USER ALIGNMENT PLAN**
- 1.2 SCIENCE AND APPLICATIONS**
  - PHYSICAL SCIENCES
  - LIFE SCIENCES
- 1.3 COMMERCIAL**
- 1.4 U.S. NATIONAL SECURITY**
- 1.5 SPACE OPERATIONS**
- 1.6 REQUIREMENTS FROM USER NEEDS**
- 1.7 FOREIGN CONTACTS**

The Lockheed logo, which consists of a stylized arrow pointing upwards and to the right, followed by the word "Lockheed" in a bold, italicized, sans-serif font.

U.S. NATIONAL SECURITY CONTACT LIST

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Personnel contacted within the Department of Defense are shown on the next two opposing pages. Most of the contacts were made in small groups of one to two people. There were a few large group presentations and in those instances only the name of the DoD host is identified. Multiple visits were made with a majority of the people on this list. In all a total of 68 people were contacted, and a total of 95 visits were made.

The Air Force contacts are shown on the opposite page. The Air Force will be one of the major users of the space station from a U.S. national security standpoint. Mission scenarios requiring the space station have been developed based on our discussions with Air Force personnel. We have reviewed these scenarios with the personnel who are interested in these specific areas and have modified them to conform to projected requirements.

There are a number of potential missions that could take advantage of the presence of a manned space station, and there is a growing interest in exploring these concepts further. Although there is no near-term mission-need statement for a manned space station, several operational missions have been identified that require the presence of man in space and these are being seriously considered by the Air Force. Other DoD users have potential uses for a manned space station as discussed on the next page.





## U.S. NATIONAL SECURITY CONTACT LIST

### U.S. AIR FORCE

HQ/XOS PENTAGON WASHINGTON, DC	LT/COL J.E. ANGELL MAJ BRUCE LUNA	SAF/ALS WASHINGTON, DC	DR. C.W. COOK COL. J. FOSTER MAJ T.W. SHORE
HQ AFSC/XR ANDREWS AFB, MD	LT/COL DAVE NEWBERN	SPECIAL ASST DIR DARPA, PENTAGON	LT/COL R.M. McCORMICK
HQ AFSC/DLAS ANDREWS AFB, MD	LT/COL V. WEBB	SD/YNV LOS ANGELES	LT/COL WIL WALKER
HQ SPACECOM/JCCS PETERSON AFB, CO	MAJ LOUIS GAROZZO COL J. HEILMANN COL FRED WISELY	STAFF SPECIALIST SPACE & ADVANCED SYSTEMS, OUSDRE PENTAGON	MR. C.O. FORSYTHE
HQ TAC/XPJS LANGLEY AFB, VA	LT/COL T. SHERMAN	DIA DC3 WASHINGTON, DC	MR. GEORGE WARNER
HQ SAC/XPF OFFUTT AFB, NE	COL G. CUDD MAJ HAL RAINIEY CAPT O. STOCKLAND	NATL SEC COUNCIL	COL GIL RYE
HQ SD/XR LOS ANGELES, AFS CA	COL. DON HARD LT/COL L. WEAVER MAJ R. ZWIRNBAUM CAPT J. SCHIERMEYER DR J. BAKER		
HQ USAF/INET WASHINGTON, DC	LT/COL JOHN B. GROSS		
HQ USAF/RDSL WA, D.C.	MAJ CHRIS SCHADE		
HQ SD, LOS ANGELES	MAJ STAN ROSEN		
AF STRAT FORCE ANAL.	COL C. HEIMACH		

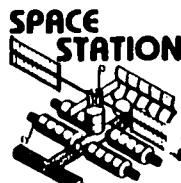
U.S. NATIONAL SECURITY CONTACT LIST  
(CONT)

Contacts were made with personnel in both the Navy and Army to determine potential mission requirements for space station applications.

The Navy has expressed strong interest in the use of the space station as a research and development platform for observation of oceanographic phenomena. The Navy has recently established a committee, chaired by RADM J.B. Mooney, Jr., to investigate the use of man in space for oceanographic observation. Although this committee focuses on space shuttle applications, it is clear that the same type of information applies to space station studies. As a result of our visits with Navy personnel, two scenarios have been developed: oceanographic observatory development laboratory and space-based-radar satellite servicing.

Army personnel are also very much interested in space applications and see potential value of a space station in support of Army missions. Their requirements, however, are more suitable to a geostationary platform than to a low-earth-orbit platform and for this reason no scenarios were developed directly supporting or involving Army missions. A manned geostationary platform is beyond the scope of the present study. It is important, however, to maintain contact with the Army and to advise them of developments in this area because it may influence their thinking on potential applications for a low-earth-orbit station.



**PROGRAMS****U.S. NATIONAL SECURITY CONTACT LIST (CONT)****U.S. NAVY**DIR NAVAL SPACE  
SYSTEMS DIV.  
OP943, PENTAGONDEP DIRECTOR  
NAVY SPACE  
SYSTEMS DIV..  
PENTAGONDIR NAVAL  
OCEANOGRAPHY  
DIV OP-952,  
NAVAL OBSERVATORYASST-ENVIRONMENTAL  
SAT. PROG. NAVAL  
OCEANOGRAPHY DIV  
NAVAL OBSERVATORY  
WASHINGTON, D.C.TECHNICAL DIR.  
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NAVY SPACE  
PROJECT (PMEL06)  
ARLINGTONSATELLITE SURVEILLANCE  
BARNAHQ, OP  
986E, PENTAGONONR-WEST  
LA JOLLA, CA

RADM W.E. RAMSEY

CAPT W.D. PEIRCE  
CDR D. DIAZRADM J.B. MOONEY, JR.  
CAPT V. JOHNSON

CAPT. DAVE HONHART

DR FRANK W. DIEDERICH  
MR. CHARLES A. GOOD

CDR BRUCE HOLLINGER

DR R. STEVENSON

**U.S. ARMY**ARMY SPACE  
PROGRAM OFFICE  
WASHINGTON, DCTRAINING AND  
DOCTRINE COMMAND  
FT. MONROE, VAIMAGERY  
INTELLIGENCE  
DIVISION  
(DAMI ISP), ASST.  
CHIEF OF STAFF  
FOR INTELLIGENCE  
HQ DEPT. OF THE  
ARMY, PENTAGONSTRATEGIC PLANS  
& POLICY DIV  
(DAMO SSP) DEP  
CHIEF OF STAFF  
FOR OPERATIONS &  
PLANS, DEPT OF THE  
ARMY, PENTAGONDAMO-RQI  
PENTAGONCOL R.A. SCHOW  
MR. W.J. MORANMR. PAUL O'KEEFE  
MR. JACK VAN SANTMAJ GARY BREWER  
LT/COL H.M. TUTTLE

CAPT YUKNIS, USA

LT/COL.(P) J. GRUBBS

FUTURE MILITARY MISSIONS

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The figure on the opposite page was taken from an article in the American Institute of Aeronautics and Astronautics journal dated 14 January 1981 and modified to introduce MILSTAR as an example. This chart was not intended to be related to manned space activity. It was developed to identify those missions to be pursued by DoD in the future for U.S. national security reasons. For the most part these missions represent improvements of existing satellite systems. In some cases the proposed systems incorporate revolutionary technology advances projected to be available in the 1990s.

The purpose of examining this chart in the present study is to identify existing military missions that could potentially benefit from the presence of a manned space station. The primary use of the manned station for these missions is in a supporting role. The station could provide a base for developing and evaluating technology and could also provide the necessary base for assembly of large antenna or other large unmanned satellites. Our analysis of these missions did not suggest replacement of an unmanned satellite by a manned system, however.



## FUTURE MILITARY MISSIONS\*

POTENTIAL FUNCTION	1980	1985	1990	1995	2000
OBSERVATION	BALLISTIC MISSILE SURVEILLANCE  DMSP  ENVIRON SURVEILLANCE	SPACE OBJECT SURVEILLANCE  MOSAIC SENSOR  JT. DoD/CIVILIAN IMPROVED DMSP - REAL TIME READOUT	ATMOSPHERIC SURVEILLANCE  IR RADAR	ADAPTIVE OPTICS  WHOLE-EARTH COVERAGE  GEO-SAT -CONTINUOUS MONITORING	MANNED STATION
COMMUNICATION	DSCS II  FLISAI	DSCS III  SURVIVABLE SATCOM (MILSTAR)		MULTI-PURPOSE FIXED/MOBILE  BATTLE MANAGEMENT  SUBAERIAL COMM	
NAVIGATION	TRANSIT IMPROVEMENT PROGRAM  GLOBAL POSITIONING SYSTEM		TACTICAL SUPPLEMENT  ADVANCED GPS AND COMMAND/CONTROL  TARGET LOCATION		

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\* AIAA  
14 JAN 81

 Lockheed

EVALUATION OF THE SPACE STATION ROLE  
IN SUPPORTING EXISTING SATELLITE SYSTEMS

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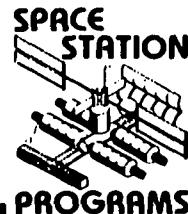
The presence of a space station will not create new military missions, but rather will provide a new means for accomplishing existing missions. For this reason it seemed appropriate to review 18 existing systems to determine if the presence of a space station would influence the ways in which these missions are performed.

The space station could provide a base for data reduction and analysis of information from remote satellites prior to transmitting the information to the ground. In this role it is possible that the station could augment the performance of existing systems. There is substantial diversity of opinion on whether or not this is a valid role for a manned system, however, and there is no identified support at this time to propose this role, as a primary operational requirement for a manned space station. There is considerable interest in evaluating the potential capability for man's involvement in this role but strictly as a research and development activity.

There is substantial agreement that the manned space station would provide an excellent research and development platform for check out and evaluation of new components as well as satellite systems. In that sense the RDT&E column on the facing page chart is intended to show the benefit in using the space based platform for development of the next generation of an existing satellite system.

Satellite servicing activities, which comprise the seven remaining columns on the chart, are clearly an accepted and significant function of the space station. It must be emphasized that satellites must be specifically designed for the repair, assembly, resupply, change out, and reconfiguration activities. Existing systems, for the most part, are not designed for space-based support. By the early 1990s, however, new generations of satellites will be launched and these should be designed for space-based satellite servicing. The role of the space station in supporting systems of this type is discussed in the next session titled Space Operations.





## POTENTIAL MILITARY APPLICATIONS OF THE SPACE STATION

SYSTEMS	AUGMENT PERFORMANCE	RDT&E	SATELLITE MUST BE SPECIFICALLY DESIGNED FOR THESE OPERATIONS				OBSERVE	DEPLOY / RECONSTITUTE	RETRIEVE
			REPAIR	ASSEMBLE / RESUPPLY	CHANGE-OUT	RECONFIGURE			
DSP	X	X							
AWS	X	X							
GPS	X		X		X			X	
IONDS	X	X						X	
DMSP	X		X	X	X	X	X		
GEODSS	X	X							
DS <sup>3</sup>	X	X	X	X	X	X	X		X
NAVSPASUR	X	X							
HOE ADVANCE SENSOR	X	X	X	X	X	X	X	X	X
PAVE PAWS	X	X							
SPASER		X	X	X	X	X	X		X
AFSATCOM	X							X	
SPACE CRUISER	X	X	X	X	X	X	X	X	X
SCF/CSOC	X								
SCS	X	X							
SHUTTLE	X		X	X	X	X	X	X	X
ELVs	X								
ADVANCED MILITARY SPACECRAFT		X	X	X	X	X	X		X

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AIR FORCE TECHNOLOGY MISSION MODEL

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An Air Force technology mission model has been developed through a joint effort with the U.S. Air Force, industry, and the American Institute of Aeronautics and Astronautics. On the preceding two pages missions were identified that are extrapolations of existing capabilities and existing requirements. The Air Force technology mission model is far less constrained. No attempt was made to limit projected missions to systems for which a mission-need statement has been developed. Rather the purpose was to project speculative systems that challenge the capabilities of our existing technology with the objective of identifying driving technologies that must be pursued near term in order that the down stream speculative missions can be considered and potentially implemented at some future date.

We have examined this classified document in considerable detail and have speculated on the potential role of a space station in assessing or augmenting projected capability for various proposed missions. This study has provided guidance in development of the scenarios contained here as well as in the classified section of this report.





## AIR FORCE TECHNOLOGY MISSION MODEL

THE AIR FORCE TECHNOLOGY MISSION MODEL HAS BEEN ASSESSED TO IDENTIFY AREAS IN WHICH THE SPACE STATION CAN FACILITATE MISSION PERFORMANCE IN THESE PROJECTED SYSTEMS.

IN ADDITION OVER 20 LOCKHEED PERSONNEL ACTIVELY PARTICIPATED IN THE USAF/AIAA MILITARY SPACE SYSTEMS TECHNOLOGY MODEL WORKSHOPS: MR. B. G. MORAIS OF LMSC IS CHAIRMAN OF THE OVERALL ACTIVITY FOR AIAA. DATA FROM THESE STUDIES HAVE BEEN INCLUDED IN OUR SPACE STATION STUDY AS WELL.

## MILITARY BENEFITS OF A SPACE STATION

There is general agreement that there are three primary areas of potential military benefits from a manned space station. Research and development missions offer the most immediate promise for beneficial return. Programs that require evaluation on orbit will benefit by the extended mission duration compared with the time available from the space shuttle. An example of such a program is Talon Gold, which can perform its mission in the 5-day shuttle flight but could realize potentially substantial additional information with a 15 day or more flight. A second program that clearly benefits from extended duration on orbit is the Navy oceanographic sensor development activity that will be discussed further in the following pages.

A second category for which a space station might benefit military uses of space is in the logistics and resupply of satellite systems. The refueling, modification, maintenance and repair, and large structures assembly are all tasks that will play key roles in satellite servicing activities. For the most part satellites must be specifically designed to take advantage of servicing capabilities, and most existing systems will not benefit from satellite servicing operations. By the time a space station is operational, however, a new generation of satellites will be in orbit and if these are properly designed, space-based satellites servicing can play an important role. It is important to evaluate space-shuttle-based servicing compared to space-station-based servicing, however, because of the constraints imposed by orbit mechanics that limit the frequency of revisit opportunities from a space station to specific satellites.

The direct involvement of a space station in operational missions is perhaps the most important, and least well defined, area for potential military benefits of a manned system. Although research and development missions and logistics and resupply missions will make use of a station if it is there, it is unlikely that requirements in these categories will provide a compelling reason for proceeding with a space station. Operational missions, on the other hand, can form a major incentive to proceed with space station development and for that reason these missions are of prime interest. It is possible that the command and control mission for the space station may provide a compelling reason to proceed with the initial phases of space station evolution.





## MILITARY BENEFITS OF SPACE STATION

- RESEARCH AND DEVELOPMENT MISSIONS
  - IMPROVED PROGRAM PERFORMANCE WITH LONGER TIME IN ORBIT.  
E.G., TALON GOLD
  - SENSOR DEVELOPMENT - MANNED INTERACTION DURING TEST.  
E.G., NAVY OCEANOGRAPHIC SYSTEMS
- LOGISTICS AND RESUPPLY
  - E.G., REFUEL ATTITUDE CONTROL, MANEUVER PROPELLANTS,  
SATELLITE SERVICING (MAINTENANCE AND REPAIR) ON ORBIT,  
AND LARGE STRUCTURES ASSEMBLY
  - NEED TO EVALUATE SHUTTLE VS. SPACE STATION
- OPERATIONS
  - COMMAND AND CONTROL.  
E.G., EXTENSION OF NATIONAL MILITARY COMMAND SYSTEM
  - SPACE OBSERVATION



**U. S. NATIONAL SECURITY  
R&D MISSION SCENARIO  
OCEANOGRAPHIC OBSERVATORY  
DEVELOPMENT LABORATORY**

 Lockheed

The Lockheed logo consists of a stylized arrowhead pointing upwards and to the right, followed by the word "Lockheed" in a bold, italicized, sans-serif font.

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OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB MISSION SCENARIC

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Personnel in the U.S. Navy have expressed considerable interest in expanding existing capabilities for surveillance of the oceanographic characteristics of the high seas. They have found that manned observation from the Apollo, Skylab, and most recently Shuttle orbiter have provided data that cannot be obtained from data recorded by remote sensors. The strong feeling is that once we understand the phenomena being observed by the unaided eye of the astronaut, we will be able to develop remote sensors or interpret the signal of existing sensors, and subsequently implement an unmanned system to detect the features of interest. Thus, the objective here is to use a combination of manned observation and remote sensor data simultaneously to establish the correlation necessary to select operational remote-sensing designs. It is presumed that manned involvement from space is required during the development phase only and that the operational phase will function in a conventional manner such as LandSat or SeaSat.

This mission is especially well suited to a space station because it combines two key elements: the requirement for manned observation and involvement in space, and the need for an extended period on orbit. Oceanographic phenomena of interest changes slowly with time and it is necessary to make measurements over a period of months in order to obtain the desired data on characteristics such as thermoclines or the presence or absence of long-wave-length deep ocean waves. The change in the characteristics of these features with time is also of particular interest. Though Shuttle-based observations have been helpful in demonstrating the need for visual observation by man in space, the flight duration is too short to provide the scope of data required for this development activity.





## OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB MISSION SCENARIO

MISSION CATEGORY: U.S. NATIONAL SECURITY

SYSTEM/PROGRAM: OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LABORATORY

OBJECTIVE:

- TO DEVELOP MULTISENSOR SYSTEMS AND EXPAND EXISTING CAPABILITIES
- TO PROVIDE MEANS FOR EXTENDED REALTIME OBSERVATION OF DYNAMIC OCEAN PHENOMENA AND CONTROL OF SENSOR POINTING AND DUTY CYCLES
- TO CORRELATE VISUAL OBSERVATIONS IN SPACE AND DATA FROM VARIOUS SENSORS
- TO PROVIDE MEANS TO REDUCE DEVELOPMENT COSTS AND TO MINIMIZE DEVELOPMENT SPANS BY MAKING USE OF MANNED CAPABILITIES
- TO PROVIDE DATA TO EVALUATE ROLE OF MAN IN AN OPERATIONAL ENVIRONMENT

SYSTEM DESCRIPTION:

LIFETIME: 3 TO 6 MONTHS PER EXPERIMENTAL SEQUENCE

10 YEAR USEFUL OPERATION

LAUNCH VEHICLE:

SHUTTLE

TRANSFER VEHICLE:

NONE REQUIRED FOR PAYLOADS HARD-DOCKED ON SPACE STATION  
TMS REQUIRED FOR CLUSTER FREE FLYER

OPERATIONAL LOCATIONS:

300 - 700 KM AT 65 DEGREES PREFERRED  
300 KM AT 28.5 DEGREES USEFUL

OCEANOGRAPHIC OBSERVATION DEVELOPMENT LAB  
(CONT)

The essence of this development lab scenario is that equipment will be repositioned, modified, or changed out while on orbit in order to assess the effect of the equipment location, pointing angle or configuration on remote sensor data. It is vital to provide the correlation with manned observation from space made from the identical position and at the same time. Thus the instruments must be located onboard the spacecraft with the astronaut making the observations. Another aspect of this development lab concept is that experimental (brassboard) sensors can be evaluated and this offers the potential of greatly reducing the time for taking laboratory concepts through the development cycle to operational configurations.

The size of the crew necessary to do the development work depends upon the type and complexity of equipment change and modifications anticipated on orbit.





# OCEANOGRAPHIC OBSERVATORY DEVELOPMENT

## LAB MISSION SCENARIO (CONT)

**SYSTEM DESCRIPTION: (CONT)**

TOTAL MASS AT OPERATIONAL LOCATIONS: TBD (BUT LESS THAN 14,000 KG)

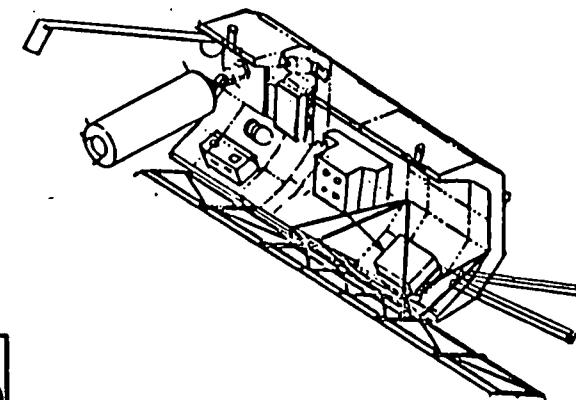
AVERAGE OPERATIONAL POWER: 'TBD (BUT LESS THAN 5 KW)

DESIRED INITIAL OPERATIONAL DATE: 1988 (SHUTTLE-BASED EXPERIMENTS)

## 1990 (SPACE-STATION-BASED EXPERIMENTS)

### GENERAL NEEDS:

- EQUIPMENT TO BE MOUNTED ON EXISTING PALLET  
(E.G., ESS OR SPACELAB PALLET)
  - LABORATORY IS TO BE CAPABLE OF SUPPORTING  
EXPERIMENTAL (BRASSBOARD) HARDWARE AND  
SENSORS
  - PHYSICAL CHARACTERISTICS:  
30FT X 14 FT DIAMETER  
UP TO 40FT ANTENNA (SORTIE) EXPANDABLE  
OR UNFOLDABLE  
UP TO 300FT ANTENNA (FREE FLYER)
  - OPERATIONAL CREW:  
2 EXPERIMENTERS MINIMUM (NO EQUIPMENT MODS)  
10 MAN CREW (TECHNICIANS)
  - DATA:  
ONBOARD DATA PROCESSING, 10<sup>3</sup> MBPS



OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB  
(CONT)

Sensor architecture should be designed to provide equipment to cover the entire ultraviolet to microwave range of radiation of interest. Sensors exist for all of these categories, but it is the design detail, the sensor size and orientation, and the combination of sensors on a single platform that are critical to this experiment. All of these features can be assessed from a sensor platform attached to the space station. The sensors could be attached to a pallet (or pair of pallets), compatible with the shuttle payload bay, and then transferred with the pallet(s) to a payload support fixture on board the space station. If a specific sensor design is incompatible with other sensors on the same payload (for instance a very large SAR antenna that blocks the field of view of an infraed detector), seperate pallets could be used, perhaps even located on different areas of the space station. This still achieves the objective of making simultaneous measurements and comparing those with visual observations.



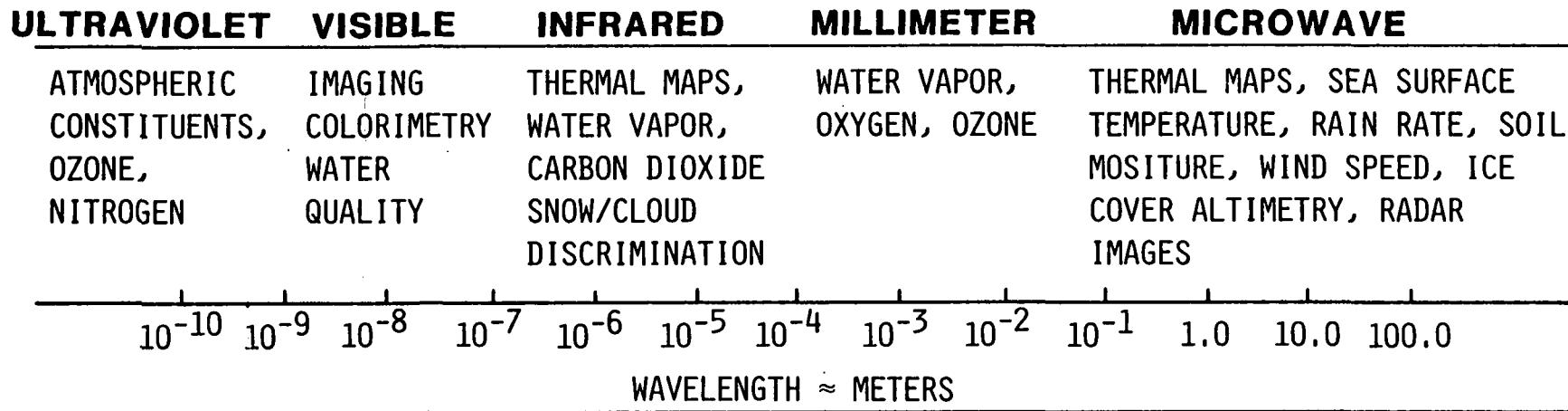


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## OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB MISSION SCENARIO (CONT)

### SENSOR ARCHITECTURE:

- SENSORS OPERATE OVER COMPLETE WAVE LENGTH SPECTRUM



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OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB CONTACTS

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The need for an oceanographic observatory development lab was highlighted by Capt. D. Honhart and Dr. R. Stevenson. The concept has received wide attention within the Navy and is an area of considerable interest and potentially of substantial value. The need for this type of program, starting with space shuttle based activities, has received attention at the highest levels within the Navy.





## OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB CONTACTS

---

### CONTACTS:

RADM J. MOONEY	CHIEF OCEANOGRAPHER, U.S. NAVY, WASH. D.C.	202/254-4318
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DR R. STEVENSON	ONR. SCRIPTS INSTITUTE OF OCEANOGRAPHY	714/452-3012
CAPT W. PEIRCE	DEPUTY DIRECTOR, NAVY SPACE	202/697-0761
CDR D. DIAZ	OFFICE OF NAVY SPACE	202/697-0761

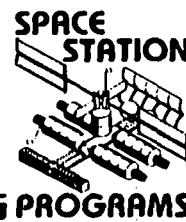


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**U. S. NATIONAL SECURITY  
R&D MISSION SCENARIO  
SPACE OBSERVATION  
DEVELOPMENT LABORATORY**

 *Lockheed*

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SPACE OBSERVATION DEVELOPMENT LABORATORY MISSION SCENARIO

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As a counterpart to the Navy Oceanographic Development Laboratory, some individuals within the Air Force have expressed strong interest in the development of multisensor systems for space observation and space object identification. The objective is to correlate sensor data with visual observations to develop a better understanding of signals from remote sensors. Just as for the Oceanographic Observation Development Laboratory, the ability to change location, orientation, and configuration of sensor equipment on orbit is key to the development of new sensor capabilities. Also, repeated observations over a long period of time are necessary to define and develop a clear understanding of the significance of remote sensor signal data. The argument in this case is not as compelling as in the oceanographic scenario because the time constraint does not appear to be as critical.





## SPACE OBSERVATION DEVELOPMENT LABORATORY MISSION SCENARIO

MISSION CATEGORY: U.S. NATIONAL SECURITY

SYSTEM/PROGRAM: SPACE OBSERVATION DEVELOPMENT LABORATORY

OBJECTIVE:

- TO DEVELOP MULTISENSOR SYSTEMS FOR SPACE OBSERVATION AND EXPAND EXISTING CAPABILITY
- TO ASSESS AND IDENTIFY THE MOST EFFECTIVE SENSOR SYSTEMS FOR SPACE OPERATIONS
- TO PROVIDE MEANS FOR EXTENDED REALTIME MANNED OBSERVATIONS AND CORRELATION OF DYNAMIC OBSERVATION DATA AND PROCEDURE AND CONTROL OF SENSOR POINTING AND DUTY CYCLES
- TO PROVIDE A MEANS TO REDUCE DEVELOPMENT COSTS AND SCHEDULES

SYSTEM DESCRIPTION:

PURPOSE: EVALUATE MULTISENSOR SYSTEMS

LIFETIME: 3 TO 6 MONTHS PER EXPERIMENT SEQUENCE

10 YEAR USEFUL OPERATION

LAUNCH VEHICLE: SHUTTLE

TRANSFER VEHICLE: NONE REQUIRED FOR PAYLOADS HARD-DOCKED TO SPACE STATION  
TMS REQUIRED FOR CLUSTER FREE FLYER.

OPERATIONAL LOCATIONS: 300 - 700 KM AT 28.5 DEGREES



SPACE OBSERVATION DEVELOPMENT LAB  
(CONT)

The objective of this experiment is to be able to change out hardware on orbit. The pallet configuration is very similar to that for the oceanographic observation laboratory. The complement of equipment is different but the physical characteristics of the sensors are basically similar. A two-man crew is adequate if sensor position and location are changed but a larger crew will be required if equipment is to be modified on orbit. One of the potential advantages of a manned space station platform is the ability to perform such equipment modifications to facilitate the data acquisition process and thereby enhance the development activities.

A major step forward in sensor development for aircraft use was achieved during the decade from 1968 through 1977 (e.g., AAFFE Program). In this effort a variety of principal investigators was allowed to take laboratory concepts into the field to demonstrate feasibility for operational systems. A substantial advance in sensor technology was achieved that would not have been otherwise possible. The use of the space station for development of sensors on a platform such as proposed here is a direct analog to the aircraft sensor development activity of the last decade.





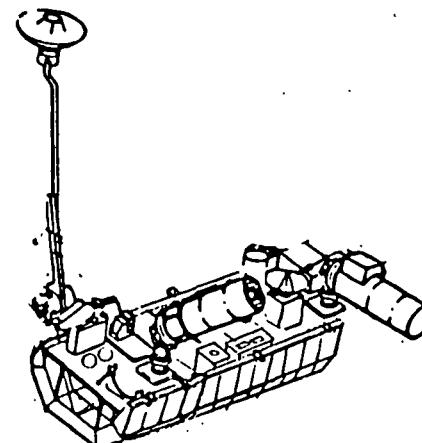
## SPACE OBSERVATION DEVELOPMENT LABORATORY MISSION SCENARIO (CONT)

### SYSTEM DESCRIPTION: (CONT)

TOTAL MASS AT OPERATIONAL LOCATIONS: TBD (BUT LESS THAN 14,000 KG)  
AVERAGE OPERATIONAL POWER: TBD (BUT LESS THAN 4 kW)  
DESIRED INITIAL OPERATIONAL DATE: 1988 (SHUTTLE-BASED EXPERIMENTS)  
1990 (SPACE-STATION-BASED EXPERIMENTS)

### GENERAL NEEDS:

- EQUIPMENT TO BE MOUNTED ON EXISTING PALLET (E.G., ESS OR SPACELAB PALLET)
- LABORATORY IS TO BE CAPABLE OF SUPPORTING EXPERIMENTAL (NOT FLIGHT OPERATIONAL) HARDWARE AND SENSORS
- PHYSICAL CHARACTERISTICS:  
30FT X 14FT DIAMETER  
UP TO 30FT ANTENNA (SORTIE)  
UP TO 300FT ANTENNA (FREE FLYER)
- OPERATIONAL CREW:  
2 EXPERIMENTERS MINIMUM (NO EQUIPMENT MODS)  
10-MAN CREW (TECHNICIANS) IF ON-ORBIT EQUIPMENT MODS ARE TO BE MADE



SPACE OBSERVATION DEVELOPMENT LAB

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## ADDITIONAL USE

This development platform can provide the means to advance current capability for space-object identification, allowing improved ability to detect and track objects such as space debris, which present a hazard to both manned and unmanned satellites. The goal for the lifetime of the space station is in excess of 15 years. The probability of impact with small debris (under 4 cm by 4 cm) is high; although these debris (from expended or deactivated rockets and satellites) are generally small, they can do substantial damage and detection might allow maneuvering to avoid impact, or, at least, preparation to minimize the effect of impact. Because these objects are too small to be detected from the ground, space-based observation is essential. Sensor technology advances are an essential part of developing this improved capability.





## SPACE OBSERVATION DEVELOPMENT LABORATORY

### ADDITIONAL USE

- DETERMINE SPACE OBJECT IDENTIFICATION (SOI) NEEDS
  - NEAR TERM
  - FAR TERM
- DEVELOP SOI CONCEPTUAL SYSTEMS
  - LWIR
  - VISUAL
  - ELECTRONIC EMISSIONS
  - RADAR
- DEVELOP AND DEMONSTRATE TECHNOLOGIES TO SUPPORT CONCEPTS
  - HIGH RESOLUTION COOLED/UNCOOLED SENSORS
  - IR/VISUAL MFP DETECTORS
  - PRECISION POINTING/TRACKING
  - ONBOARD DATA PROCESSING HARDWARE/SOFTWARE
- PLAN SOI SYSTEM DEVELOPMENT
  - OPTIMIZE DEVELOPMENT PROGRAM SCOPE AND TIMING
  - PLAN VERIFICATION AND DEMONSTRATION, INCLUDING ANY NECESSARY MANNED FLIGHT ROLE IN DEVELOPMENT/TEST/OPERATIONAL SYSTEM(S)

SPACE OBSERVATION DEVELOPMENT LAB  
CONTACTS

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Several individuals have expressed strong interest in a sensor development laboratory concept, but this area does not enjoy the broad based support that was found for the oceanographic development laboratory. However, it is a logical and potentially vitally important type of activity that can make effective use of space station capabilities. For that reason it has been included here as one of the potential key missions for a space station.





## SPACE OBSERVATION DEVELOPMENT LABORATORY CONTACTS

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HAMPTON, VA.

804/827-3601



## IMPACT ON NASA STATION FROM OCEANOGRAPHIC AND SPACE OBSERVATION DEVELOPMENT LABS

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These two national-security mission scenarios are typical of the missions that support the use of the NASA station as a research and development facility. The payloads will be designed to be compatible with space-shuttle pallets, and thus establish the requirement for the space station to directly support attached payloads of this configuration. A need for ability to change equipment configuration and orientation imposes the need for easy shirt-sleeve access to the equipment module or to key elements of the equipment module from the main space station laboratory area. These typical missions also indicate that a crew of two to ten technicians must be accommodated during the course of the experiment activities. The technicians will not necessarily be part of the basic space station crew.





## IMPACT ON NASA STATION

FROM OCEANOGRAPHIC DEVELOPMENT LAB AND SPACE OBSERVATION DEVELOPMENT LAB

- TYPICAL MISSIONS SUPPORT THE ROLE OF NASA STATION AS A NATIONAL SPACE R&D FACILITY
- THEY ESTABLISH REQUIREMENT TO SUPPORT:
  - SHUTTLE-COMPATIBLE EQUIPMENT PALLET
  - SHIRT-SLEEVE ENVIRONMENT FOR EQUIPMENT MODULE
  - TECHNICAL CREW OF 2 TO 10 EXPERIMENTERS/TECHNICIANS





## **TASK 1—MISSION REQUIREMENTS**

- 1.1 USER ALIGNMENT PLAN**
- 1.2 SCIENCE AND APPLICATIONS**
  - PHYSICAL SCIENCES
  - LIFE SCIENCES
- 1.3 COMMERCIAL**
- 1.4 U.S. NATIONAL SECURITY**
- 1.5 SPACE OPERATIONS**
- 1.6 REQUIREMENTS FROM USER NEEDS**
- 1.7 FOREIGN CONTACTS**

The Lockheed logo features a stylized arrow or 'V' shape pointing upwards and to the right, positioned above the word "Lockheed" in a bold, italicized, sans-serif font.

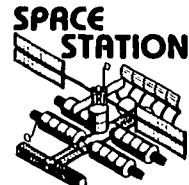
OPERATIONS OVERLAP

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Space-based activities will support users from science, applications, national security, and commercial areas. The distinction between various categories of space operations is based on the type of activity to be performed, which will reflect the assimilated needs and define the operations overlap of the specific end users. An even stronger distinction is imposed by the location of space operations (e.g., on-board, near the space station, or far distant). Since much of the activity will not be on-board, space operations are discussed in terms of orbit mechanics constraints rather than user category or activity.

It is recognized that flight crew time-line constraints are important along with power requirements and other considerations. However, until missions are more clearly defined, remote operations will impose maximum impact on the station architecture and thus are emphasized at this time.

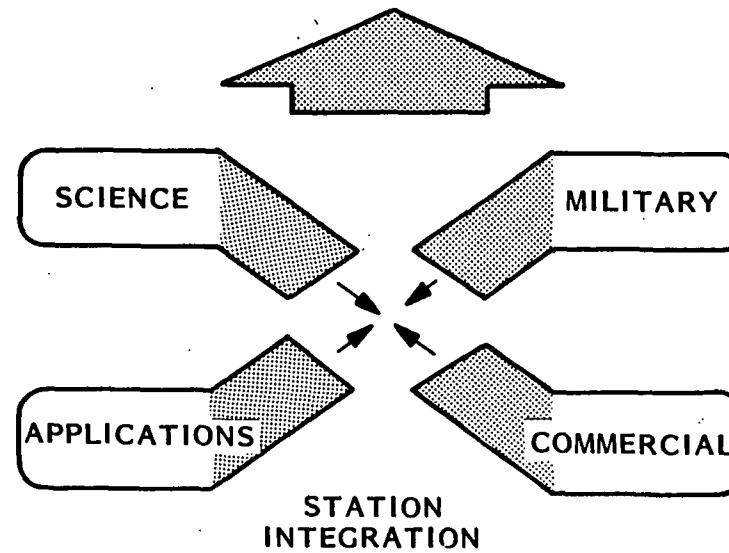
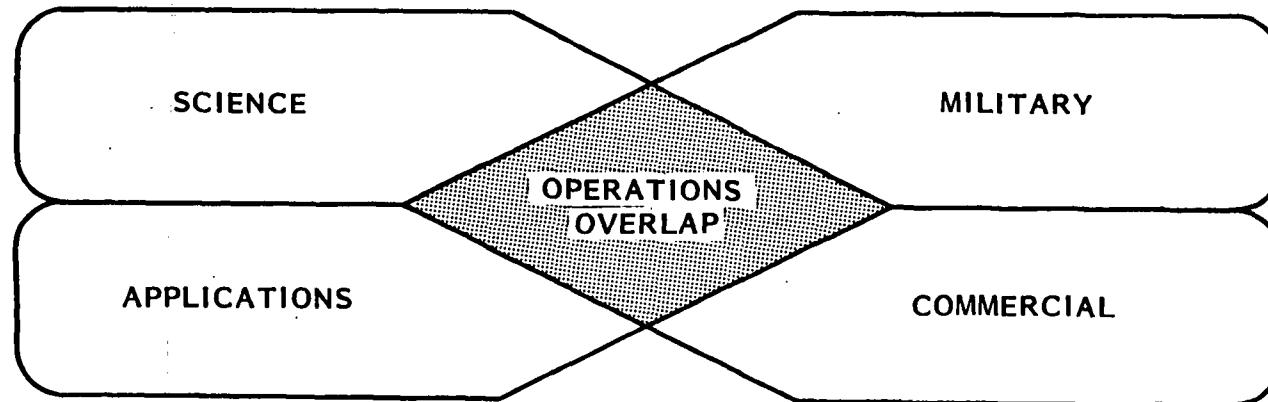




PROGRAMS

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## OPERATIONS OVERLAP



DERIVATION OF MISSION REQUIREMENTS FOR SPACE OPERATIONS

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Potential operational missions such as satellite maintenance, assembly of large space structures, servicing of free-flying experiment platforms, and storage of dormant satellites near the space station have been discussed with user contacts in all mission areas (science, applications, national security, and commercial). Mission requirements for space operations to be supported by the space station were defined through analysis of user mission requirements. A series of scenarios has been developed defining key characteristics of each mission category.

The above process has also yielded a list of potential non-NASA endorsers of space station opportunities.



## DERIVATION OF MISSION REQUIREMENTS FOR SPACE OPERATIONS

- POTENTIAL USER COMMUNITY FOR SPACE OPERATIONS DEVELOPED THROUGH USER CONTACTS IN ALL MISSION CATEGORIES.
- OPERATION NEEDS FURTHER REFINED THROUGH REPEATED USER CONTACTS.
- SPACE OPERATIONS REQUIREMENTS IDENTIFIED THROUGH ANALYSIS OF MISSION REQUIREMENTS AND ATTENDANT OPERATIONS NEEDS.
- SCENARIOS DEVELOPED TO TEST AND IMPLEMENT DEFINITION OF OPERATIONS REQUIREMENTS.

SPACE OPERATIONS

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Operations from the space station are of two basic groups: onboard and remote. Onboard operations may include extravehicular activity (EVA) as well as internal vehicular activities (IVA) on the space station. Onboard operations also include docking maneuvers and stage assembly for orbit transfer vehicles (OTV) and payloads mounted on or tethered to the space station. Spacecraft servicing at the station is a fundamental operation that complements remote servicing. Early proof-of-technology demonstrations can be performed both internally and with attached hardware. Similar operations can be expected for research and development, which also includes construction and assembly in an attached mode.

Remote operations include servicing and support of all types of space operations in association with free-flying spacecraft. Remote operations would also include automated functions performed by an unmanned spacecraft servicing or docking with a remote satellite, even though the activities may be controlled and actively guided by a crewperson on-board the space station.

Requirements for onboard station operations are developed in response to various missions scenarios discussed in other sections. The space station will be designed to support onboard operations, and the station configuration will be developed to minimize inherent limitations. Some fundamental characteristics of the station (e.g., minimum gravity level or local contamination levels) will make onboard station operations unsuitable for certain payloads. Such specialized payloads will be placed on free-flying satellites and remotely supported. Orbit mechanics places several fundamental restrictions on remote operations and these limitations are the focus of the first subsection on space operations.





## SPACE OPERATIONS

- ON-BOARD STATION OPERATIONS
  - HEALTH AND WELFARE OF STATION ITSELF
  - SUPPORT OF ON-BOARD EXPERIMENTS, ASSEMBLY, CONSTRUCTION, DOCKING AND TRANSFER, ETC.
  
- REMOTE OPERATIONS
  - SPACECRAFT SERVICING
  - SUPPORT FOR EXPERIMENTS, ASSEMBLY, CONSTRUCTION, DOCKING, AND TRANSFER, PRODUCTION OPERATIONS, ETC., ON FREE-FLYING SPACECRAFT

THE ENERGY REQUIRED TO SUPPORT SATELLITES IN LOW EARTH ORBIT (LEO) FROM THE SPACE STATION PLACES PRACTICAL CONSTRAINTS ON:

- ACCESSIBILITY
- REVISIT FREQUENCY
- TYPE OF SERVICING OPERATIONS

SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

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Seven representative systems were examined (see chart on facing page). Each system was studied for alternative ways to perform on-orbit operations and several individual cases were developed as a subset to each individual mission.

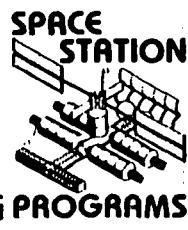
The missions were selected to represent various categories of space operations. In addition, they were chosen to represent the range of activities that would take place near the space station as well as remote from it.





## SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

- LARGE STRUCTURES ASSEMBLY (LARGE ANTENNA FOR SPACE RADAR)
- ASTRONOMY PLATFORM SUPPORT
- SPACE TELESCOPE MAINTENANCE
- SPACE BASED RADAR (ITSS) MAINTENANCE
- PROMPT SATELLITE REPLACEMENT
- SHUTTLE CREW RESCUE VEHICLE
- GEO SATELLITE RESUPPLY



# CONSTRAINTS IMPOSED BY ORBIT MECHANICS

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1.5-11

## CATEGORIES OF SPACE OPERATIONS

The orbital mechanics implications of supporting hard-docked payloads or captive free-flyers on the space station are no different than the traditional problems of controlling variable-mass systems and present no new fundamental constraints here. Tethered satellites, however, have some interesting characteristics that warrant attention.

Four categories of remote operations need to be considered. First, satellites with the same inclination, orbit plane, and phasing as the space station, and within a few miles of the station altitude, are readily accessible at all times and line-of-sight communications and control are possible. This first category includes the concept of free-flying clusters that may contain production facilities for material processing in space or free-flying platforms for various scientific experiments. Since these satellites are close to the altitude of the space station, relative nodal drift occurs slowly and can be corrected with minor, infrequent altitude adjustments and using the altitude control system.

The second category covers support of satellites in nearby inclinations (within 15 deg from the space station inclination). The bounds are provided by the capability of the orbit transfer vehicle (OTV) and the size of payload to be transported. By restricting attention to transfers at nodal coincidence with altitude changes of less than a few thousand miles, the delta V required for a roundtrip is less than 15,000 ft/sec, and the existing Centaur wide-body OTV could be used. For small payloads, the Teleoperator Manuevering System (TMS) could also be used.

The third category involves orbit transfer from the space station to any satellite in low earth orbit (LEO). The delta V required for a roundtrip maneuver will reach about 30,000 ft/sec, which could require a prohibitively large quantity of propellant unless OTV staging or advanced electric propulsion systems are used. Thus, at least for early station operations, satellites in this category will probably be serviced by one-way missions only. It may be possible to recover the OTV in the new (satellite) orbit or to refuel it at that orbit, and fly it back to the space station.

The support of geosynchronous earth orbit (GEO) satellites is also possible from a space station. In fact, the energy to reach GEO is less than the maximum energy required to support LEO satellites at non-optimum transfer times, since minimum energy transfer from one LEO to another requires a 3 burn manuever with apogee over twice GEO altitude.





## CATEGORIES OF SPACE OPERATIONS

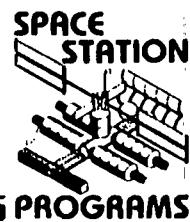
PAYLOAD AND SATELLITE SERVICING WILL BE GROUPED INTO FIVE CATEGORIES:

### ON-BOARD OPERATIONS

- 1- HARD DOCKED PAYLOADS, CAPTIVE FREE-FLYER, AND TETHERED SATELLITES

### REMOTE OPERATIONS

- 2- SUPPORT OF SATELLITES IN LOCAL STATION VICINITY
- 3- SUPPORT OF SATELLITES IN NEARBY INCLINATIONS AT NODAL COINCIDENCE
- 4- UNIVERSAL SUPPORT OF LEO SATELLITES
- 5- UNIVERSAL SUPPORT OF GEO SATELLITES



**CATEGORY 1  
HARD DOCKED PAYLOADS,  
CAPTIVE FREE-FLYERS,  
TETHERED SATELLITES**

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1.5-15

CAPTIVE FREE-FLYER

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While the impact of hard-docked payloads on the orbit mechanics of the space station presents no conceptual restraints, a hard-docked payload is subjected to the transient dynamic loads transferred through the station structure. This can have an adverse effect by disturbing the desired very low-g environment which some users (such as materials processing producers) assume they must have for extended periods of time. One way to obtain very low-g is to mount the experiment on a free-flying satellite which orbits the station (see category 2). This has the disadvantage that manned interaction with an experiment (or production process) on a frequent basis is difficult, or at the least inconvenient.

An alternative is to mount the payload on a support pallet contained inside a support structure envelope on the space station. While work is performed on the payload, it is hard-mounted to the station. During payload operation when low-g is desired, all supports are removed. An aerodynamic fairing can be used to create an even higher vacuum in its wake and to minimize the already very small drag forces. The effect of the surrounding space station structure on the vacuum level, as well as general contamination effects, will have to be examined for each specific configuration. Hardware based on such concepts have flown on many satellites, usually as a solid sphere inside a spherical container, and were used to provide signals for an inertial guidance and control system. The extension of this concept to a free-floating 20,000-lb payload with furnaces and radiators, as well as requirements for power and communication, may be nontrivial, but it is an appealing approach with potentially substantial benefits.

This approach should work well, unless the space station is part of a tether system in which the station is not located at the center of mass.

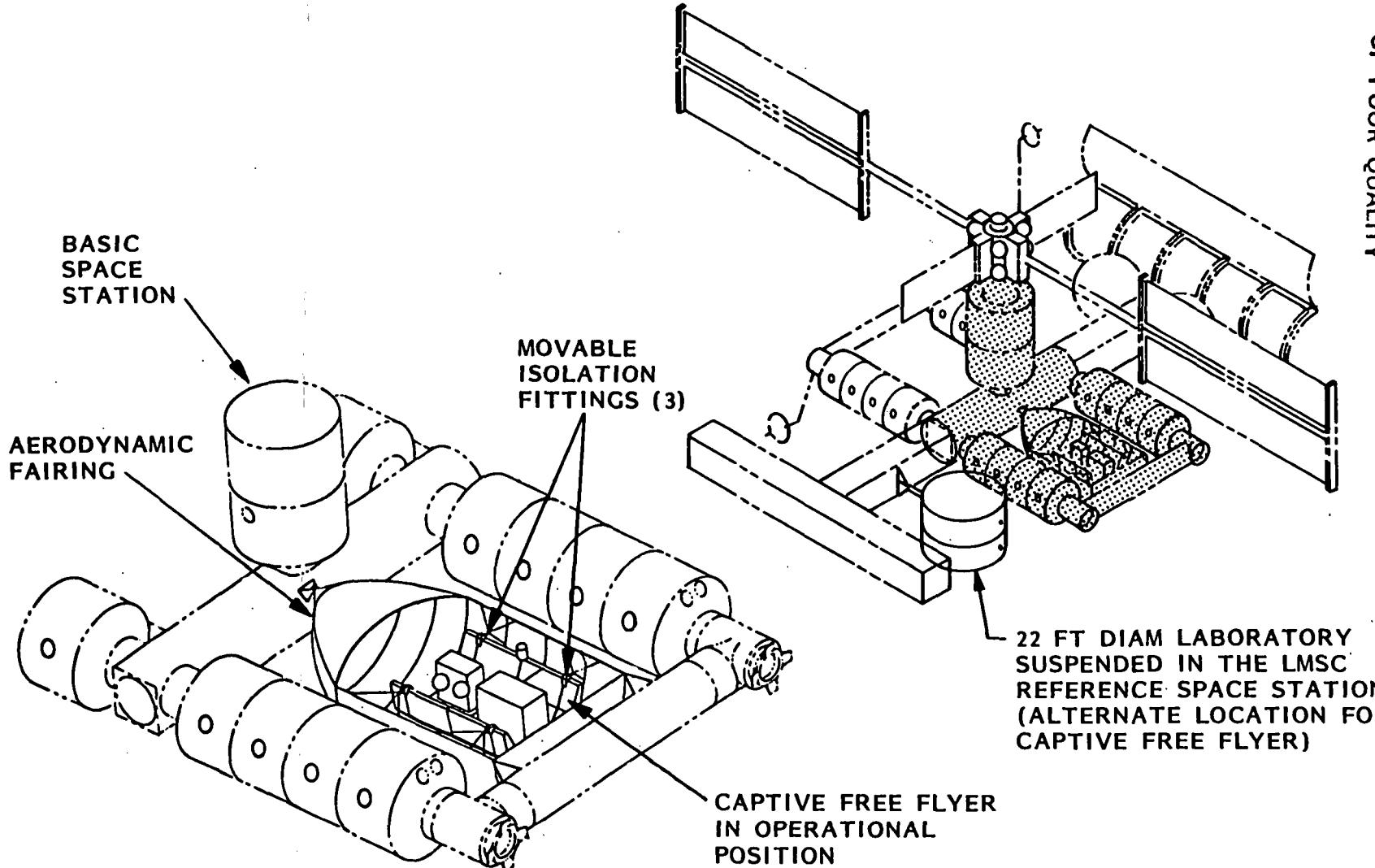




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## CAPTIVE FREE FLYER

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## TETHERED PAYLOADS

An alternative to free-flying satellites is to have individual payloads tethered to the space station. Individual satellites could be linked in a horizontal tether with the center of mass at the same orbit altitude as the space station. In addition, vertical tethers could be deployed to place payloads in the same orbit plane, but several kilometers above and below the orbit altitude.

The sketch on the facing page shows payloads tethered to the space station. The drag on the first payload is less than the drag on the second, which, in turn, is less than the drag on the third, and, in turn, all have a drag less than that of the space station. Thus the tether remains in tension. Minor perturbations may create unwelcome movement of the payloads, thereby requiring some onboard control system. The dynamic behavior would have a very long period and the disturbances would not be difficult to counteract. The reactor on the leading tether provides power to the magneto plasma dynamic (MPD) thrusters, which provide drag makeup for the entire system. By placing the reactor on a fairly long tether, with the external tank (ET) as a reaction mass, the safety of the system is enhanced, since cutting the tether puts the reactor into an elliptical orbit with an apogee at least 49 km higher. The MPD thrusters will have to be carefully positioned to avoid plume contamination on payloads, or the eight km long leading tether could be used as an Alfven engine, pulling the whole system along. Other arrangements should be considered, including systems with only payloads on tethers. In that case, drag makeup would be supplied periodically by the central station, and payloads could be reeled in during drag makeup operations.

The advantage of this concept is that payloads can be supplied power, communication, two-axis stabilization, and possibly even fluid transfer on a continuous basis, through the tether system. Thus, onboard control requirements for each payload are minimal, which could significantly reduce complexity and cost. The advantages compared to a hard-docked concept are that a lower disturbance level could be achieved and contamination of the low-g environment or of the atmosphere surrounding the spacecraft would be avoided. Very long tethers could be considered if low-level artificial gravity fields are desired, and if precise control over the gravity level is required. Another advantage is that the payloads have nearly the same benefits of the low-contamination environment for a free-flying satellite, while remaining in close proximity to the space station at all times. Servicing and equipment changeout can be performed onboard the station by reeling in the tethers by trams that crawl along the tethers.

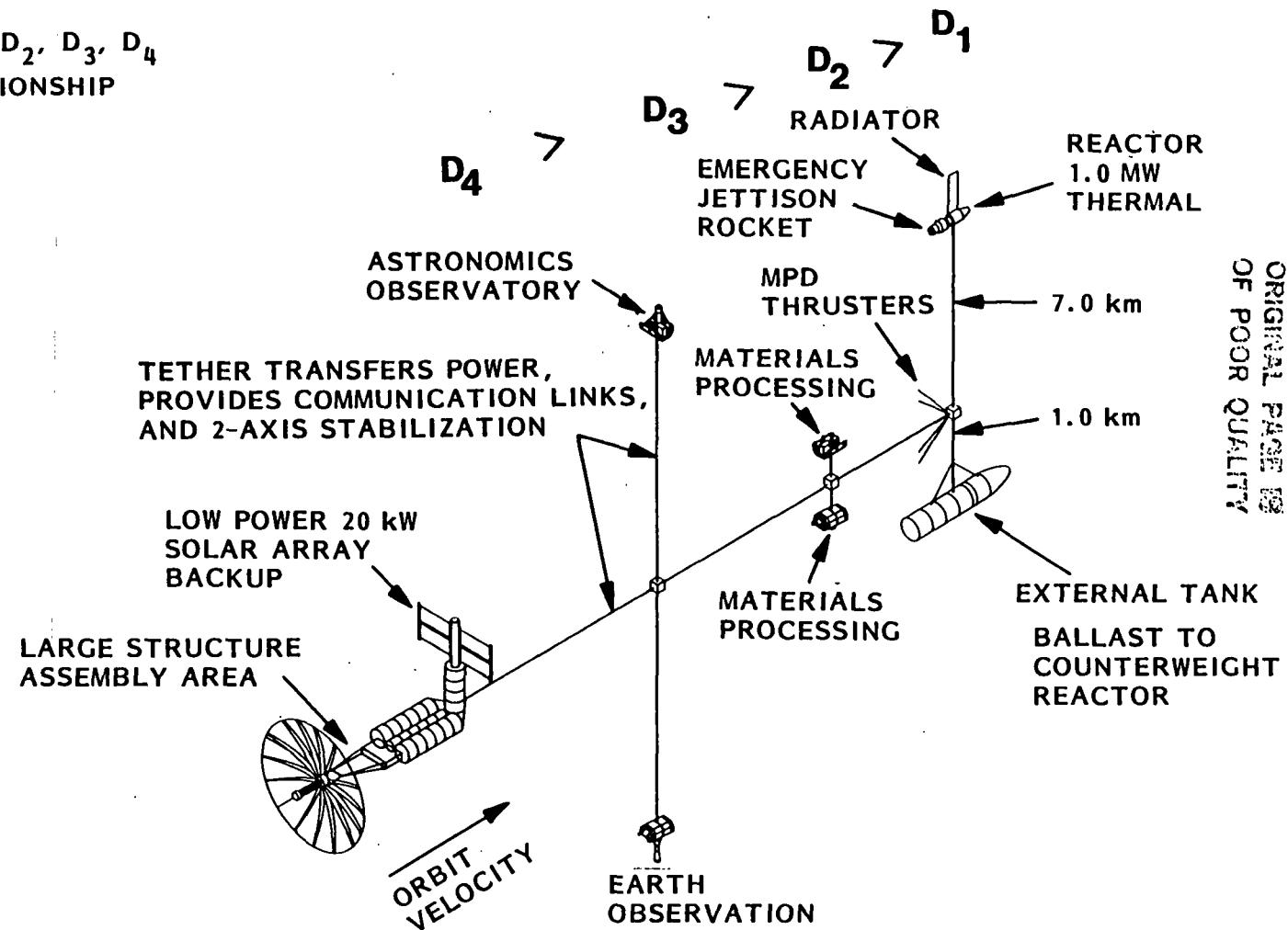




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## TETHERED PAYLOADS

DRAG FORCES  $D_1, D_2, D_3, D_4$   
MUST HAVE RELATIONSHIP  
 $D_1 < D_2 < D_3 < D_4$



CATEGORY 1--SUMMARY

---

Tethered payloads and captive free-flyers are attractive alternatives to free-flying satellites since central services (power, communication, two-axis stabilization, passive retrieval) can be provided by the space station and cost trades should prove favorable. The concept of a captive free-flyer is that the payload pallet and equipment drift entirely free, but are contained entirely within the space station structure during operation. Activities such as docking and orbit decay due to drag will cause relative motion between the space station and the captive free-flyer which will limit the duration of free flight (frequent or continuous drag makeup by the station can help). Also the need to transmit power and provide a data link may dictate that cables be used which will also perturb the isolated free flight. For tethered satellites, the tether loads are very low and electric power losses are minimal even for very small conductor sizes; thus the weight of the tether is small if the tether length is less than 10 km. For some applications, tether lengths greater than 100 km are feasible. The tether provides a continuous load on the payload, however, and the gravity levels (a function of tether length) must be reconciled with mission requirements.





## CATEGORY 1 - SUMMARY

HARD DOCKED PAYLOADS, CAPTIVE FREE-FLYERS, AND  
TETHERED SATELLITES

- ENERGY REQUIRED: FORCES REQUIRED TO REEL IN THE TETHERS ARE SMALL BUT SYSTEM TRADES ARE REQUIRED TO COMPARE WITH TMS ENERGY REQUIREMENTS FOR SERVICING FREE-FLYERS.
- REVISIT FREQUENCY: UNLIMITED (CONSTRAINED ONLY BY REQUIREMENTS FOR OTHER ON-BOARD PROGRAMS)
- OPERATIONS: UNLIMITED (EXCEPT FOR LOW - BUT FINITE - GRAVITY FIELD DEVELOPED IN TETHER SYSTEMS)
- EXAMPLES:
- EARTH RESOURCES
  - ASTRONOMICAL OBSERVATORY
  - MATERIAL PROCESSING
- ORBIT TRANSFER VEH: NONE REQUIRED. PAYLOADS HARD DOCKED OR CAPTIVE ARE PHYSICALLY ATTACHED TO PLATFORM - AT MOST EVA MAY BE REQUIRED. PAYLOADS ON TETHERS ARE REELED IN TO STATION, OR TRAM CAN TRAVEL ON TETHER TO DEPLOYED PAYLOADS
- PAYLOAD LOCATION: ATTACHED VIA TETHER (METERS TO KILOMETERS LONG) TO STATION



## CATEGORY 2

### -SUPPORT OF SATELLITES IN LOCAL STATION VICINITY

- “CLUSTER FREE-FLYER”
- EXPERIMENTS, PRODUCTION OPERATIONS ,  
ASSEMBLY/CONSTRUCTION

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1.5-23

FREE-FLYER IN CIRCULAR EARTH ORBIT

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Two approaches will be considered for keeping satellites in the vicinity of the space station: use of the drag characteristics of the free-flyer satellite, and use of an elliptic orbit.

The first concept (shown on the facing page) is to use the drag characteristics of the free-flying satellite (also called a cluster free-flyer) to control its position relative to the space station. At day zero, the satellite is approximately 4 nmi above the altitude of, and 35 deg in advance of the station. The 35 deg limit was selected to provide line-of-sight capability for communication between the space station and the satellite, thereby minimizing the complexity of the communication system for the free-flyer. The 35 deg limit combined with the satellite drag fixes the maximum altitude of the free-flyer. Both the station and the satellite orbit in the same direction and are coplanar. Because the satellite is initially slightly higher in altitude, its period is slightly longer and, to an observer on the station, it appears that the satellite is moving backward. Because of aerodynamic drag, the free-flying satellite gradually decreases its altitude and, after about 15 days its orbit will have decayed to that of the space station. The satellite is now 35 deg behind the space station. The orbit of the free-flyer will continue to decay and, since its altitude is now less than that of the space station, its period will be shorter. To an observer on the space station, the free-flyer appears to catch up and pass below the station. At the end of thirty days the free-flyer will be at a point 35 deg in advance of the space station. At this point, the free-flyer will be reboosted by onboard propulsion to a position identical to its starting point and the process will be repeated. Corrections will be made to the nodal drift to insure that the cluster free-flyer, on the average, remains coplanar with the space station. The cycle time for this process is 30 days for a high-drag free-flyer, and may increase to 90 or more days for a configuration with a lower ballistic coefficient. Solar flare activity will also affect cycle time. The advantage of this process is that reboost is not required until after the 30 or more days, and thus one obtains a maximum duration, zero- g environment.

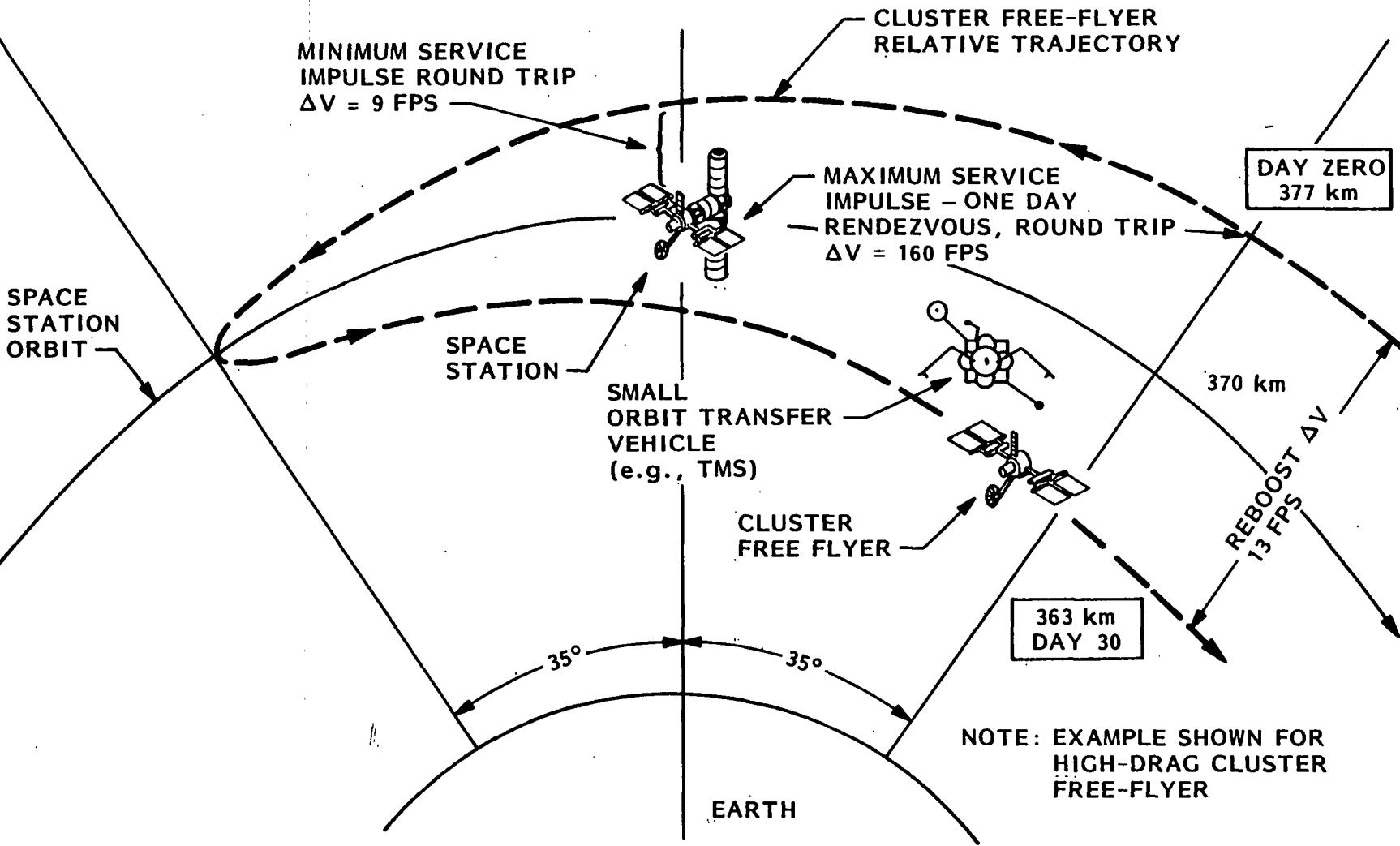
At its most extreme point the free-flyer will be about 2,500 miles from the space station. The one-day transfer can be performed using the TMS, or the satellite on-board propulsion could be used to return to the station halfway through the reboost at negligible delta V penalty.





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## OPTION 1-FREE-FLYER IN CIRCULAR EARTH ORBIT



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FREE-FLYER IN ELLIPTICAL EARTH ORBIT

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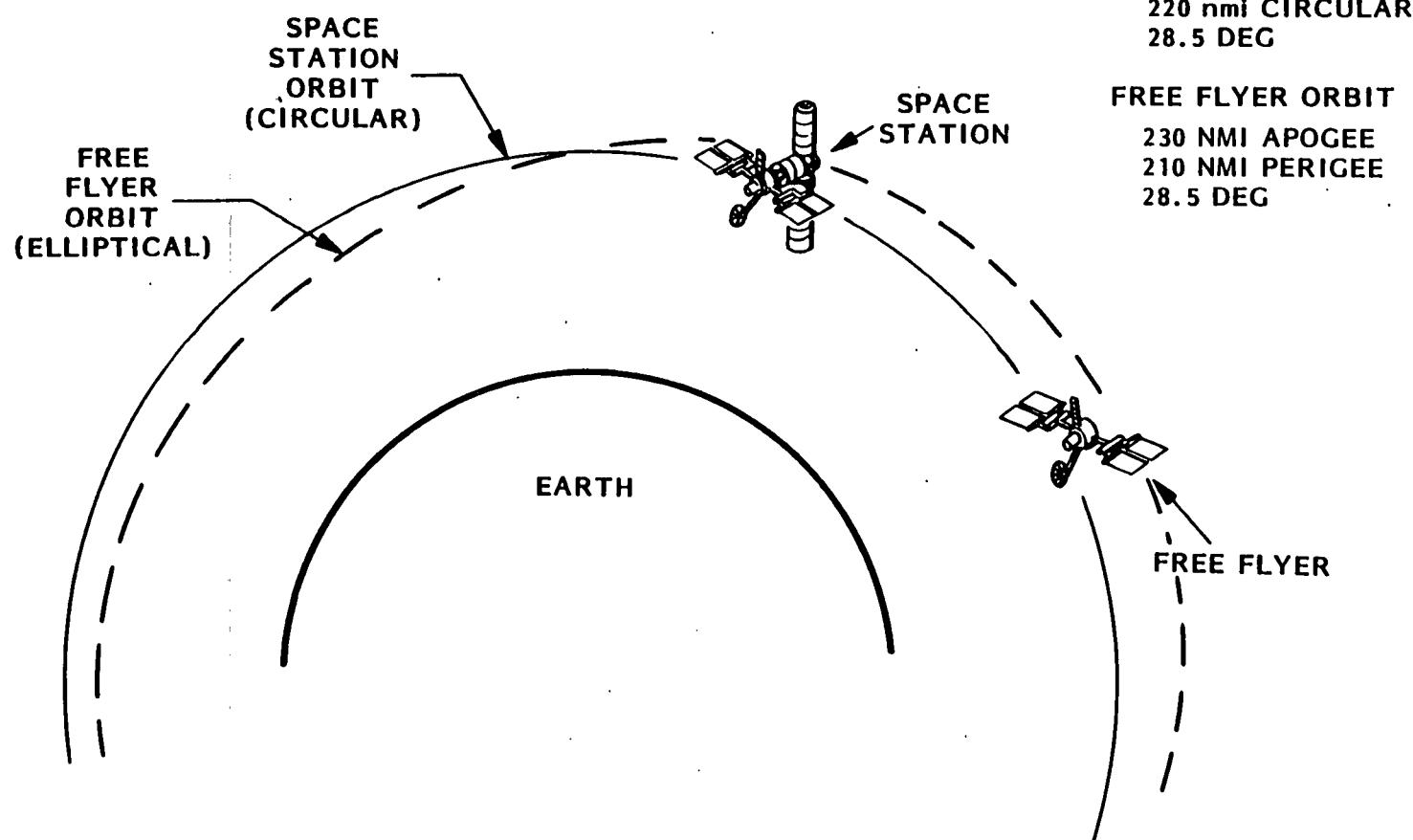
The second means to achieve a system in which free-flying satellites orbit the space station is to place the free-flyer in an elliptical orbit of identical period to that of the space station. The apogee could be 230 nmi and the perigee 210 nmi if the station is at 220-nmi circular. To an observer on the space station, the free-flyer appears to orbit the space station. As in the preceding case, the space station is assumed to continuously maintain its orbit by use of drag makeup via onboard propulsion (e.g., conventional thrusters, ion thrusters, electromotive forces on tether).

In this mode, the free-flyer will maintain its position relative to the space station through frequent thruster firings to provide drag makeup. This may be a disadvantage of this approach compared to option 1, since the interval of undisturbed flight is probably shorter. If the drag makeup thruster firings are not detrimental to payload functions this option is advantageous since the free-flyer remains closer to the station (compared to option 1).



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## OPTION 2- FREE FLYER IN ELLIPTICAL EARTH ORBIT



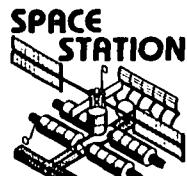
FREE-FLYER TRAJECTORY AS SEEN FROM SPACE STATION

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To an observer on the space station, a free-flying satellite in an elliptical orbit having the same mean altitude (semimajor axis) as the station will appear to be in an elliptical orbit about the space station. For a free-flyer in a 28.5-deg inclination orbit with an apogee of 230 nmi and a perigee of 210 nmi, the figure on the facing page shows the relative orbit around a 28.5 deg, 220 nmi space station. Data for two cases are presented. For the apsidal alignment case, the free-flyer remains at least of 10 nmi from the station. For the case in which the station and free-flyer are periodically colocated, the two bodies will come arbitrarily close (depending on starting conditions) once each orbit. A minimum separation distance would be advisable.

In both cases, the free-flyer is very close to the station at all times (40 nmi maximum separation in the example) and the free-flyer can be reached within 90 min (one revolution). This may have some advantages compared to the cluster free-flyer concept described earlier. However, more frequent drag makeup maneuvers are required for the elliptical orbit concept and this be a disadvantage for certain payloads.

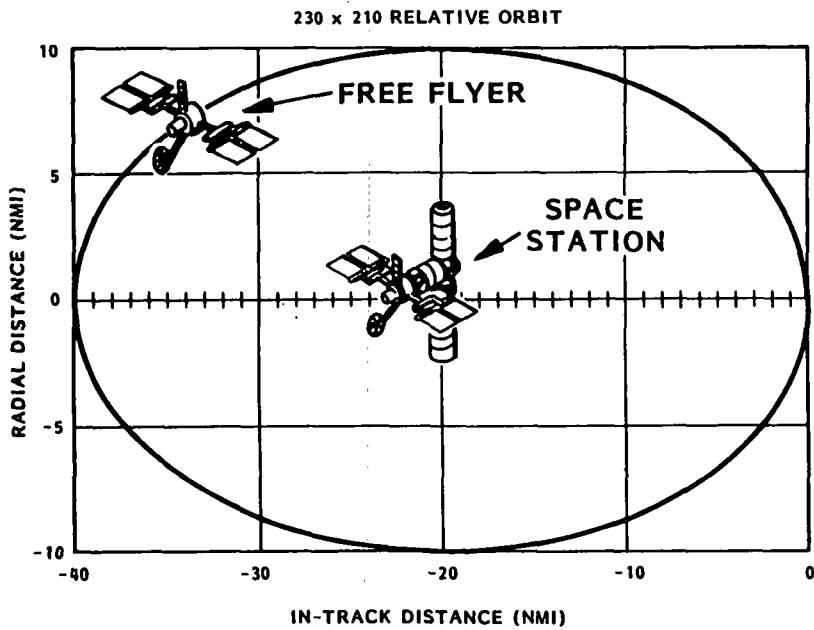
The apogee and perigee of the free-flyer orbit can be changed, and this would simply change the magnitude of separation distance from the station. If the perigee is too low, drag effects may require excessive propellant to maintain proper orbit relative to the station.



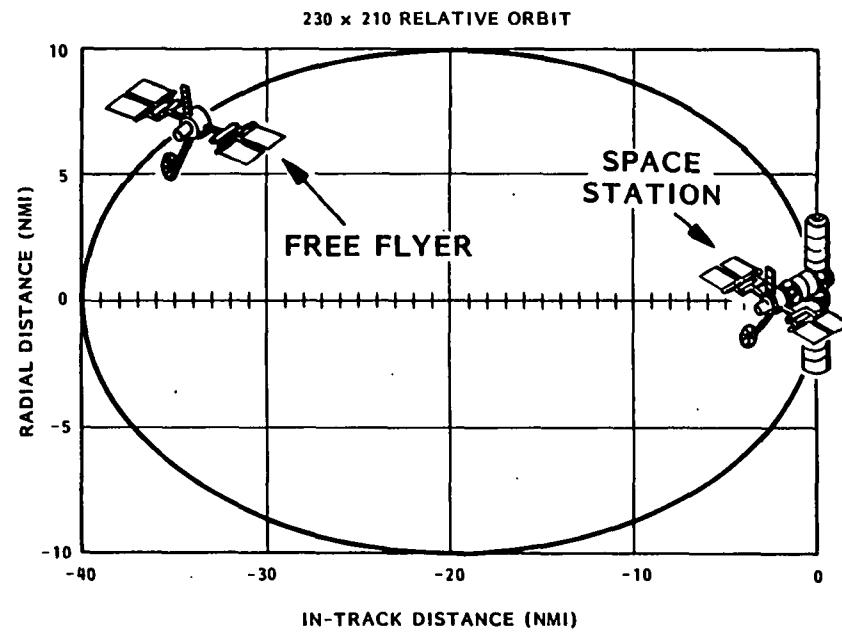
PROGRAMS

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## FREE-FLYER TRAJECTORY AS SEEN FROM STATION



APSIDAL ALIGNMENT



PERIODICALLY COLOCATED

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CATEGORY 2 -- SUMMARY

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Apart from payloads attached to the station, satellites that remain in the local of the space station are an important group of vehicles to be supported. There are many ways for a free-flying satellite to remain in the station vicinity; two primary concepts have been discussed in this section. There are no extreme constraints on the revisit frequency, nor are there constraints on the type of operations that may be performed in this environment. The dwell time at the satellite being serviced is limited only by the constraints of the life support system for manned operations or by the characteristics of an unmanned transfer vehicle. Other satellites in other orbits have severe constraints on the dwell time available for all support operations.

The energy required to reach the free-flying satellite from the space station is low and it is entirely feasible to consider moving the free-flying satellite to the space station for more complex operations. The free-flyer can be returned to its operational orbit at any time without significant penalty. Again, this is not true for other types of servicing operations discussed later.

The only restrictions imposed on these free-flyers is that satellites in this group must be coplanar with the space station and must be within a few nautical miles of the station altitude. This imposes constraints on the type of satellites that can be considered since operational requirements dictate selection of other orbit characteristics for many missions. It is even possible for the station itself to temporarily desert the cluster (e.g., due to tethered momentum transfer operations), as long as the station can compensate or nodal drift, etc. (this is most simply done by planning a sequence of operations that keep the average and final station altitudes equal to the initial station and cluster altitude).





## CATEGORY 2 - SUMMARY

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SUPPORT OF SATELLITES IN LOCAL STATION VICINITY

ENERGY REQUIRED:  $\Delta V < 160$  FPS

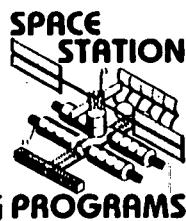
REVISIT FREQUENCY: UNLIMITED

OPERATIONS: UNLIMITED -- EXCEPT FOR CAPABILITY LIMITS  
OF TMS OR OTV  
EXAMPLES: --

- ON-ORBIT CONSTRUCTION OF  
SPACERCRAFT
- ASTRONOMY PLATFORM

ORBIT TRANSFER VEH: TMS TYPE

SATELLITE LOCATION: SAME INCLINATION AS STATION  
ALTITUDE WITHIN A FEW NM FROM STATION ALTITUDE  
30 TO 90 DAY INTERVAL BETWEEN REBOOST MANEUVERS



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## CATEGORY 3

### -SUPPORT OF SATELLITES IN NEARBY INCLINATION AT NODAL COINCIDENCE

- EXAMPLES:
- SPACE TELESCOPE
    - SCHEDULED MAINTENANCE
  - ITSS SPACE-BASED RADAR
    - SCHEDULED MAINTENANCE

 Lockheed

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1.5-33

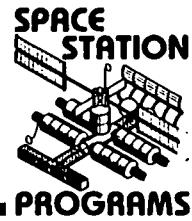
SPACE-BASED SATELLITE SERVICING ENVELOPE

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The operational capability of an OTV is a function of its total impulse (controlled by the propellant and engine configuration), the vehicle's inert weight, presence or absence of an aerobraking system, payload to be carried, and whether the payload is to be transferred in a placement mission, a retrieval mission, or a combination of both. Given these characteristics, one can compute the volume of space that can be reached by the specific OTV. All satellites within that volume could be supported by the space station with a space-station-based OTV. This assumes, of course, that the satellite is designed to be serviced or otherwise supported by the space station.

Specific satellites passing through the service volume of the OTV will change as a function of time. Understanding this change is essential to define the capabilities and usefulness of space-based satellite servicing. In this section, we will consider OTVs comparable to the Centaur wide body, modified as a reusable system. For energy levels required for orbit transfer at nodal coincidence, aerobraking systems are beneficial, but not required. A reusable OTV is highly desirable for economic reasons.

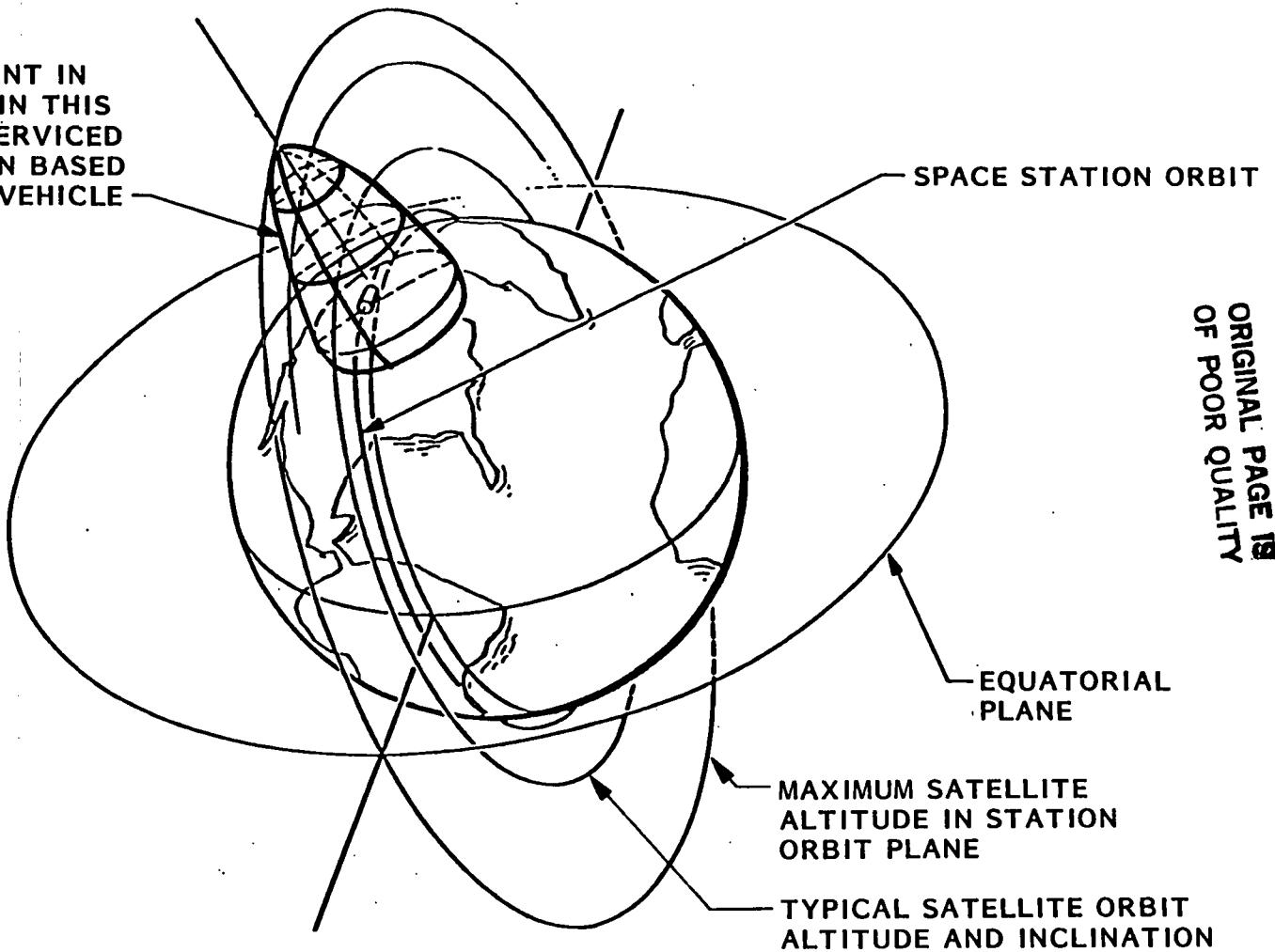




LMSC-D889718

## SPACE-BASED SATELLITE SERVICING ENVELOPE AT A GIVEN INSTANT OF TIME

AT A GIVEN INSTANT IN  
TIME SATELLITES IN THIS  
VOLUME CAN BE SERVICED  
BY SPACE-STATION BASED  
ORBIT TRANSFER VEHICLE



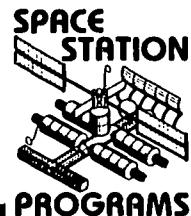
ORBITAL TRANSFERS WITH AEROBRAKING

---

Aerobraking is an emerging technology that offers great potential for expanding the capability of OTVs by increasing the usable range without increasing propellant requirements. Preliminary studies have been performed by several contractors and NASA centers and, based on available data, it is reasonable to assume that an aerobraking system would add approximately 3,000 lb. to the inert weight of the OTV. This weight increase is offset by a substantial gain in delta velocity during orbit transfer. The actual benefit from the aerobraking maneuver depends on details of the specific orbit transfer. Studies indicate that the maximum gain from aerobraking is limited to 7,000 ft/sec. and this limit has been used in the analysis which produced the results displayed in the following pages.

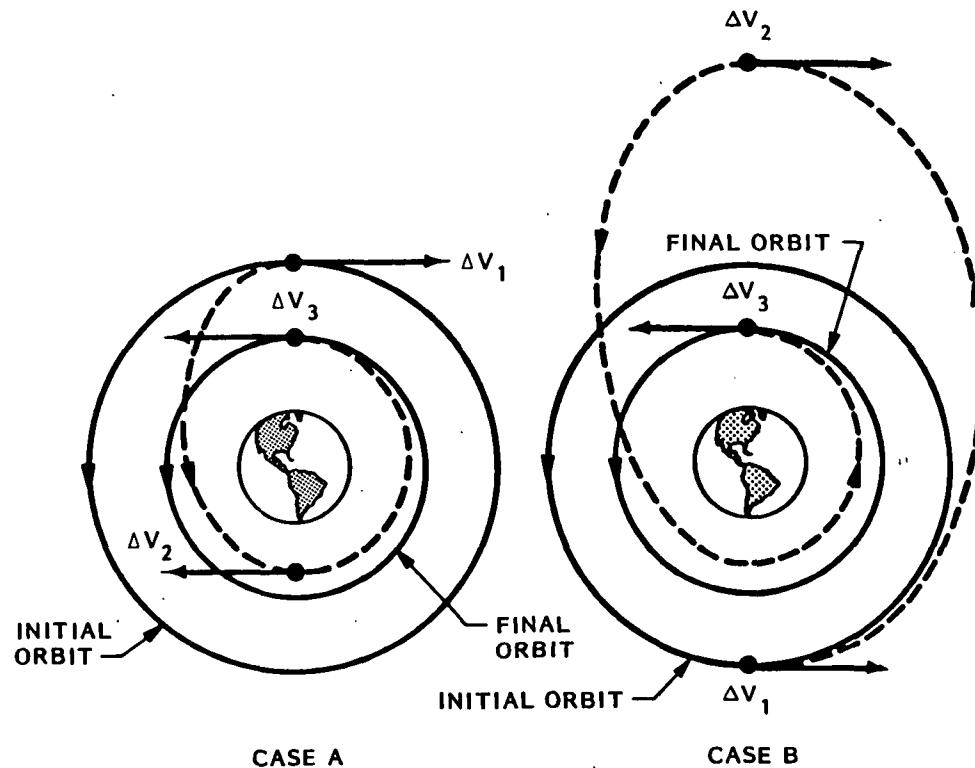
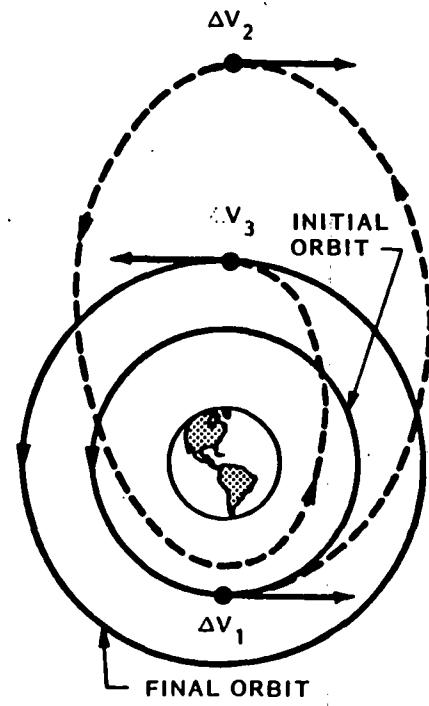
Aerobraking can be used on both ascent and return transfers as shown on the facing page. For low-energy transfers, the Hohmann two-burn trajectory provides the minimum energy transfer. In this regime, aerobraking is useful only on descent (OTV return, case A); a modified two-burn trajectory is used, with most or all the intermediate burn energy coming from aerobraking. As energy levels increase, the three-burn trajectory becomes more economical (generally when the plane change exceeds 25 deg. or so) and a more complex orbit transfer path is followed. Aerobraking in this regime to reduce the energy required for both ascent and return (see payload placement and OTV return, case B). The apogee is increased as energy requirements for the transfer are increased (e.g., making large plane change). Ultimately, the unconstrained transfer involves a second burn at infinity and the transfer time becomes infinite. In the analysis contained here, the apogee was limited to 50,000 miles to constrain the orbit transfer time to 35 hr. maximum. Allowing the apogee increase would have only a modest effect on the results contained herein and would not alter any trends or conclusions reached.





LMSC-D889718

## ORBITAL TRANSFERS WITH AEROBRAKING



PAYLOAD PLACEMENT

OTV RETURN

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 Lockheed

**TYPICAL PROPELLANT WEIGHT VERSUS DELTA VELOCITY  
FOR A 10,000-LB PAYLOAD**

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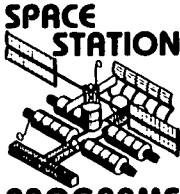
The propellant required to achieve a given change in velocity is a function of the OTV characteristics and payload to be carried. On the facing page, data are shown for an OTV with an inert weight of 3000 lb for the basic structure and equipment plus a propulsion system weight equal to 0.11 times the propellant weight. This is equivalent to a mass fraction of 0.87 for high propellant weights and to 0.70 for small propellant loads. This is consistent with a design for a cryogenic transfer vehicle with no provision for aerobraking. Another set of curves is shown for an OTV with the structure and equipment weight increased to 6000 lb. The added inert weight is to account for an aerobraking system. These figures represent typical capabilities and a specific design will yield somewhat different results. The specific impulse of 440 is consistent with current capabilities for a cryogenic propulsion system.

Four cases are examined: ascent and return with a 10-klb payload, ascent empty and return with a 10-klb payload, ascent with a 10-klb payload and return empty, and a one-way transit (ascent only) with a 10-klb payload.

In combining the curves for cases 1 and 2, it is assumed that the delta V for a one-way ascent is half that for roundtrip cases. For example, if a one-way transfer, case 1, requires 10,000 ft/sec, then cases 2, 3, and 4 require 20,000 ft/sec. The quantity of propellants for cases 1 to 4 are then 19, 75, 60, and 45 thousand pounds, respectively, for an OTV with aerobraking.

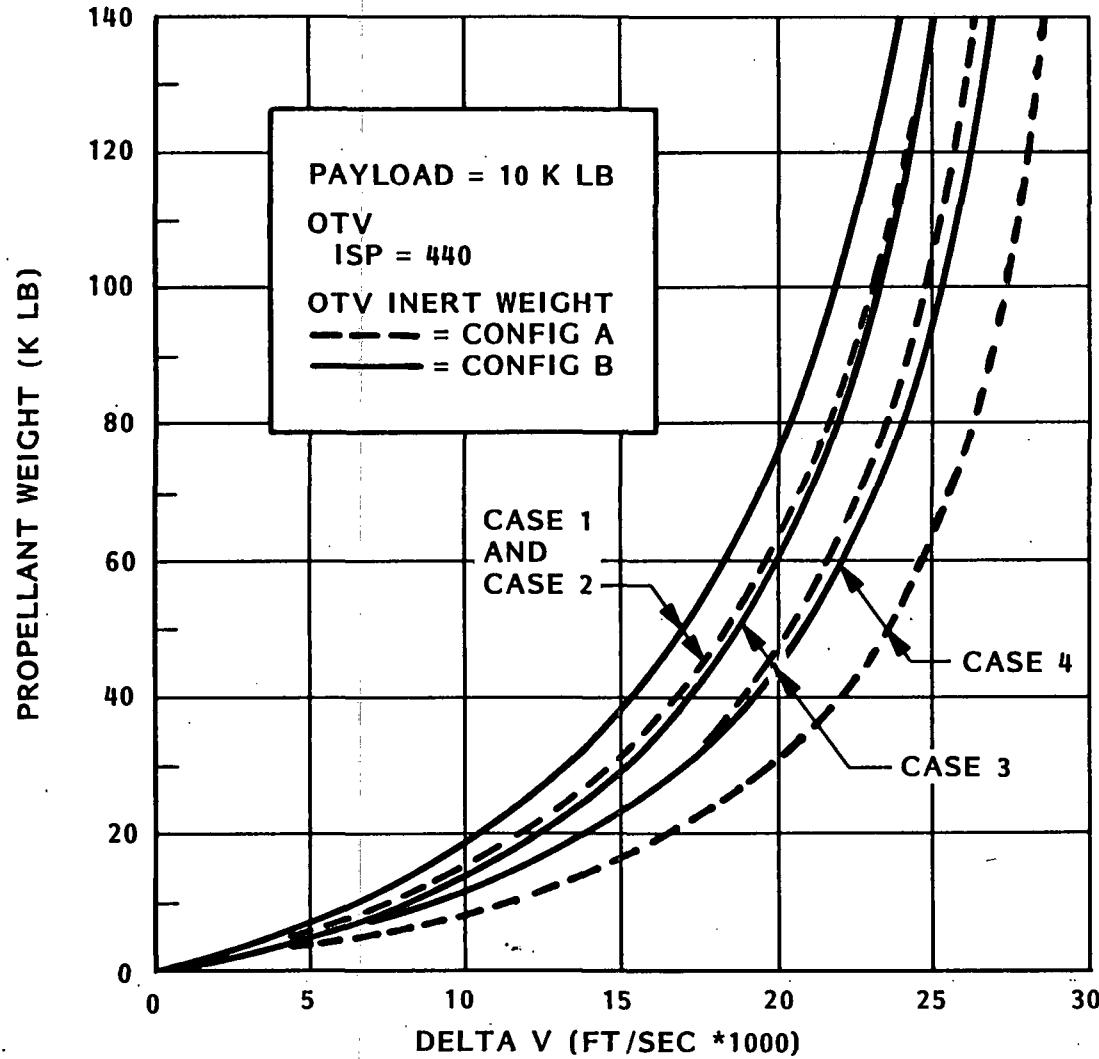
The 10-klb payload was selected because it is representative of small payloads of interest to science, applications, and commercial research users. It is also typical of a minimum weight for a manned capsule.





LMSC-D889718

## PROPELLANT WEIGHTS VS $\Delta V$ FOR 10K LB PAYLOAD



### CASE

- 1 - ONE WAY (ASCENT)  
WITH PAYLOAD
- 2 - ASCEND WITH PAYLOAD,  
RETURN WITH PAYLOAD
- 3 - ASCEND EMPTY, RETURN  
WITH PAYLOAD
- 4 - ASCEND WITH PAYLOAD,  
RETURN EMPTY

### OTV INERT WEIGHT

CONFIG A  
STRUCTURE, EQUIPMENT  
WITHOUT AEROBRAKE 3,000 LB  
PLUS  
PROPULSION SYSTEM  
MASS FRACTION = 0.90

CONFIG B  
STRUCTURE, EQUIPMENT  
WITH AEROBRAKE 6,000 LB  
PLUS  
PROPULSION SYSTEM  
MASS FRACTION = 0.90

EXAMPLE:  
CONFIG B WITH 45 K LB PROP.  
STRUCTURE, ETC. 6,000 LB  
PROPULSION SYS 5,000 LB  
TOTAL 11,000 LB

TYPICAL PROPELLANT WEIGHT VERSUS DELTA VELOCITY  
FOR A 24,000-LB PAYLOAD

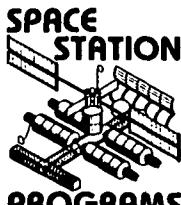
---

Similarly, when the payload weight is raised from 10-klb to 24-klb, four cases are examined: ascent and return with a 24-klb payload, ascent empty and return with a 24 Klb payload, ascent with a 24-klb payload and return empty, and a one way transit (ascent only) with a 24-klb payload.

In combining the curves for cases 1 and 2, it is assumed that the delta V for a one way ascent is half that for a round trip. For example, if a one-way transfer, case 1, requires 10,000 ft/sec , then cases 2, 3 and 4 require 20,000 ft/sec. The quantity of propellants for cases 1 to 4 are then 35, 142, 105, and 67 thousand pounds, respectively, for an OTV with aerobraking.

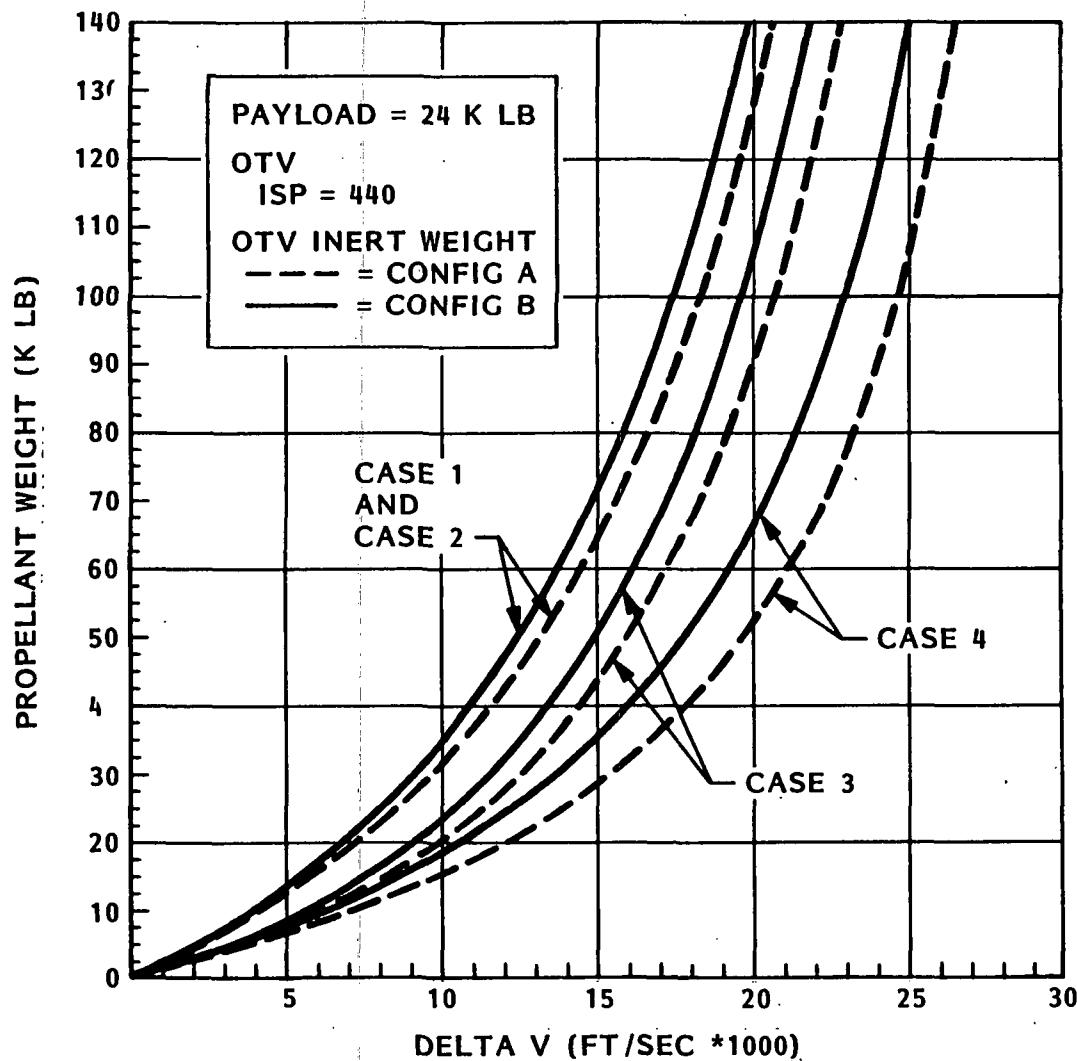
The 24-klb payload was selected because it is representative of a satellite of interest to users in U.S. national security.





LMSC-D889718

## PROPELLANT WEIGHTS VS $\Delta V$ FOR 24K LB PAYLOAD



### CASE

- 1 - ONE WAY (ASCENT)  
WITH PAYLOAD
- 2 - ASCEND WITH PAYLOAD,  
RETURN WITH PAYLOAD
- 3 - ASCEND EMPTY, RETURN  
WITH PAYLOAD
- 4 - ASCEND WITH PAYLOAD,  
RETURN EMPTY

### OTV INERT WEIGHT

#### CONFIG A

STRUCTURE, EQUIPMENT  
WITHOUT AEROBRAKE 3,000 LB  
PLUS  
PROPULSION SYSTEM  
MASS FRACTION = 0.90

#### CONFIG B

STRUCTURE, EQUIPMENT  
WITH AEROBRAKE 6,000 LB  
PLUS  
PROPULSION SYSTEM  
MASS FRACTION = 0.90

#### EXAMPLE:

CONFIG B WITH 45 K LB PROP.  
STRUCTURE, ETC. 6,000 LB  
PROPULSION SYS 5,000 LB  
TOTAL 11,000 LB

ORBIT TRANSFER BY TETHER DYNAMICS

---

There are alternatives to using conventional propellants for orbit transfer. Ion engines and magnetoplasma dynamic (MPD) thrusters are two commonly considered approaches. Both require high power levels which can be supplied by a nuclear reactor. The high ISP (about 10,000 for the MPD) makes this approach very efficient; the disadvantage is that the forces are very low and transfer times are long (about 6 months to a year for transfer to GEO). For low delta V requirements where transfer times of a few days are acceptable, this approach should be given serious consideration.

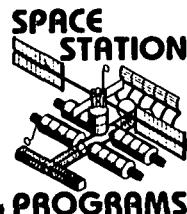
A less conventional, but more intellectually stimulating approach is to use a tether release to provide energy for some or all of the first burn delta V. The concept shown on the facing page is discussed fully in the report "Utilization of the External Tanks of the Space Transportation System," UCSD Workshop, 23-27 Aug 1982; in Ch III, Joseph Carroll discusses tether concepts.

In the concept shown, two masses are joined by a tether variable in length from a few hundred meters to a few hundred kilometers. The tether mass is a small fraction of the system mass if the tether is less than 100 km. Obviously, the longer the tether the greater the apogee of the upper mass after release. A conventional second burn can be used to circularize at final orbit. The lower mass will probably reenter if the tether is of reasonable length and if the initial configuration is in LEO (about 400 km). Thus using the Shuttle, or an expendable external tank, as the lower reaction mass has attractive possibilities.

Another possibility is to drive power up a tether. Current through a tether cutting the Earth's magnetic field generates a small electromotive force, comparable to an MPD thruster, which can increase the altitude of a satellite. The plasma environment will support a maximum of about 1.5 amps per kilometer of tether which produces a thrust of 0.02 lb. Thus a 10 km tether operating at 10 KV can produce 0.2 lb. with a power consumption of 15 KW. This is 2.5 times the force that the MPD thruster produces for the same power consumption (these effects change for high altitude or high inclination orbits). While this approach has been considered for drag makeup, it could also be used for orbit transfer when long transit time is acceptable.

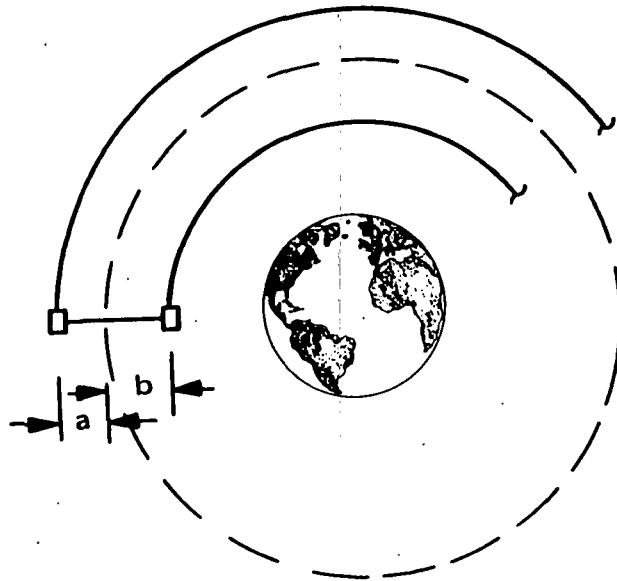
All of these concepts should be seriously considered in any system trade for study  
space-based operations





## ORBIT TRANSFER VIA TETHER DYNAMICS

FOR EQUAL MASSES  $a = b$



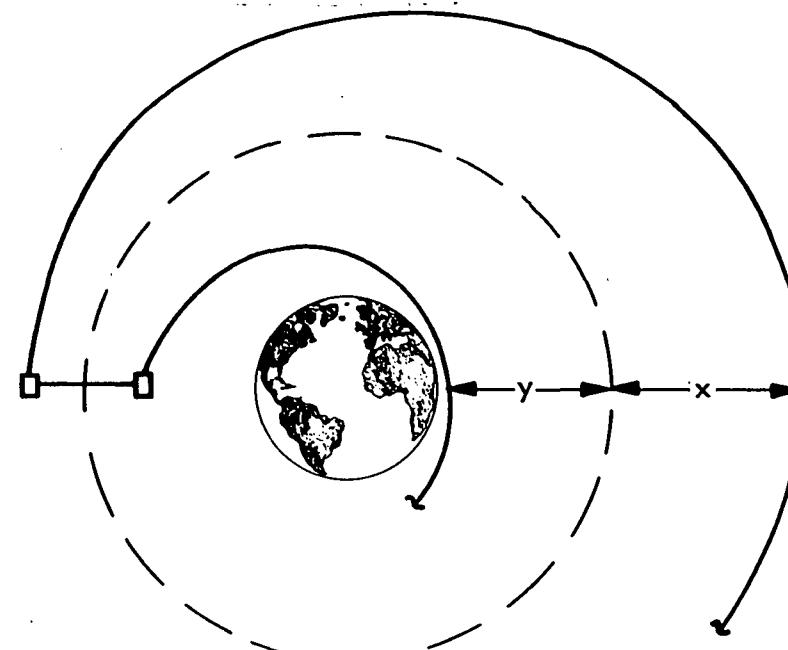
PRE-RELEASE  
BOTH MASSES ARE IN CIRCULAR ORBIT

IF TETHERED MASSES ARE NOT  
OSCILLATING AT TIME OF  
RELEASE

$$x = 7a, y = 7b$$

IF TETHERED MASSES ARE  
LIBRATING, RELEASE AT  
PEAK OF 60 DEG SWING:

$$x = 13a, y = 13b$$



POST-RELEASE  
MASSES ARE IN ELLIPTICAL ORBIT

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MINIMUM DELTA VELOCITY REQUIRED FOR ROUND TRIP  
BETWEEN SPACE STATION AND SATELLITE

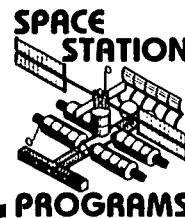
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Contours of constant delta V are shown on the facing page for roundtrip orbit transfers involving a combination of altitude and inclination change. These computations assume that the space station is at 220-nmi circular orbit. These data are valid for any space station inclination.

For cases in this regime, aerobraking is effective only on return missions, because orbit transfer involves comparatively small plane changes. The added complexity and weight of the aerobraking systems must be traded against propellant saved. For servicing missions up to 15-deg plane change at low altitude (less than a few thousand nautical miles), aerobraking systems are not required and they do not appear to offer dramatic enhancement. Cases in which aerobraking has a dramatic impact will be discussed later.

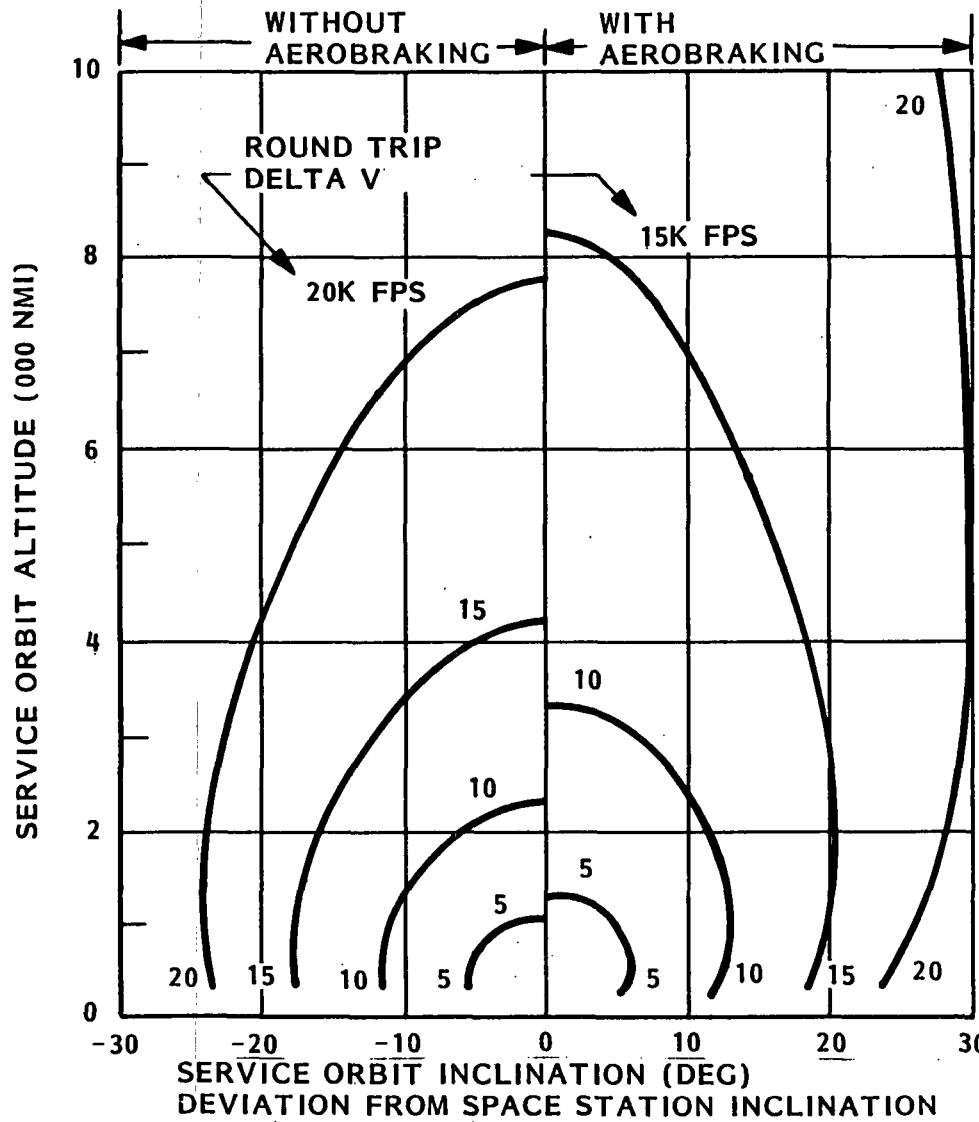
These curves assume there is no delay at the satellite operational altitude. Since the transit time is on the order of hours each way, the effect of nodal drift is negligible. If there is an extended delay to perform operations on the satellite at operational altitude, the energy required for the roundtrip transfer can be substantially affected, as discussed in the following pages.





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## MINIMUM DELTA V REQUIRED FOR ROUND TRIP BETWEEN SPACE STATION AND SATELLITE



SPACE STATION:  
220 NMI CIRCULAR  
NO DELAY AT SERV.  
ORBIT

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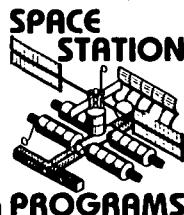
EFFECT OF NODAL DRIFT OF CIRCULAR ORBITS

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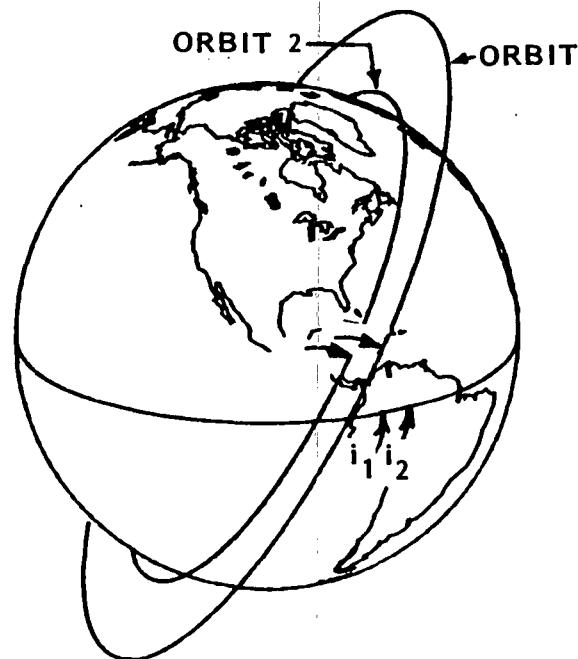
From our discussions, we found that many users did not recognize the effect of nodal drift and its impact on energy required for orbit transfers. The minimum energy transfer between satellites in two different orbits occurs when both orbits cross the equator at the same point (nodal coincidence). The relationship between two orbits changes as a function of time, and the interval between nodal coincidences can be substantial.

Two satellites with orbits at the same inclination but different altitudes also experience relative nodal drift. The plane change required to transfer from one orbit to another at a different altitude but with the same inclination will vary from zero at nodal coincidence to a maximum equal to twice the inclination when the satellites are 180-deg. out of phase. The minimum plane change to transfer from a satellite in one orbit to a satellite in another at a different inclination occurs at nodal coincidence and is equal to the difference in inclinations.

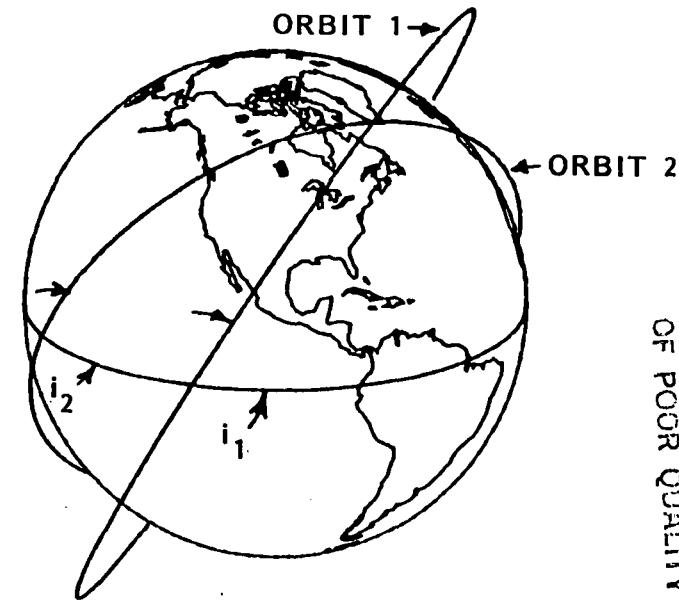




## EFFECT OF NODAL DRIFT OF CIRCULAR ORBITS AT SAME INCLINATION BUT WITH DIFFERENT ALTITUDES

TIME  $t = 0$ 

ORBIT 1 AND ORBIT 2 ARE COPLANAR  
BOTH HAVE SAME INCLINATION ( $i_1 = i_2$ )

TIME  $t = T$ 

ORBIT 1 AND ORBIT 2 ARE NOT COPLANAR  
BOTH HAVE SAME INCLINATION ( $i_1 = i_2$ )

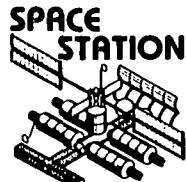
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INTERVAL BETWEEN NODAL COINCIDENCES OF A 28.5-DEG.  
SPACE STATION AND SATELLITE

---

The time interval between successive nodal coincidences of orbits for a space station and a satellite is a function of inclination and altitude of the space station and satellite. For a space station located at 220-nmi circular and 28.5-deg. inclination, contours of constant time between nodal coincidences are shown on the facing page. Since the nodal regression of satellites at high altitudes is very small, the minimum interval between nodal coincidences occurs with satellites in high Earth orbit. Satellites which have orbits very close in altitude to the space station have the longest interval between nodal coincidences. For this case, the minimum interval is about 50 days. For satellites in a 600-nmi orbit at 28.5-deg., the interval more than doubles. For satellites in nearly the same altitude as the station, the interval between nodal coincidences can be years. For instance, the interval for a 300-nmi, 28.5-deg. satellite is 23 months.

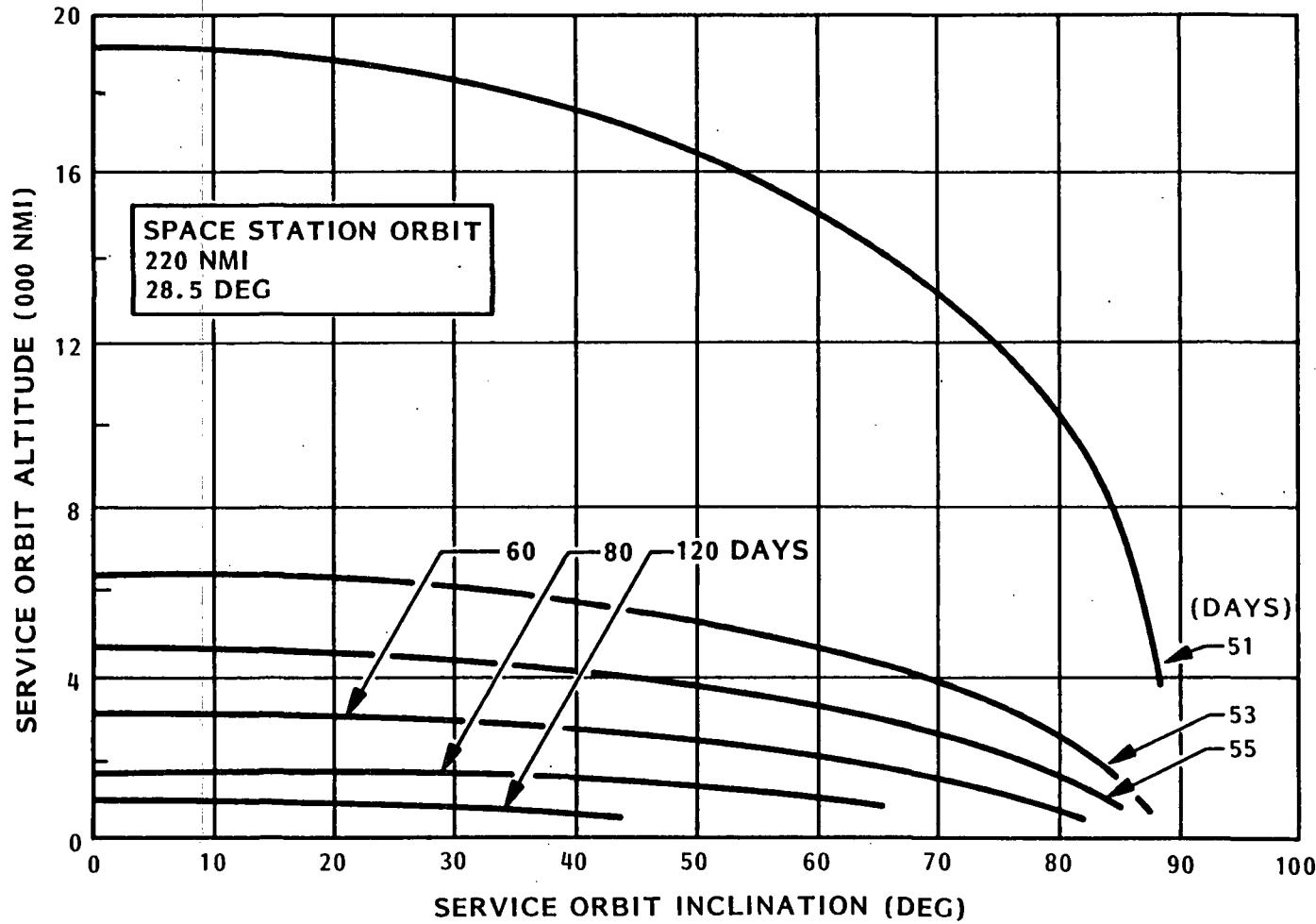




PROGRAMS

LMSC-D889718

## INTERVAL BETWEEN NODAL COINCIDENCES FOR A 28.5 DEG SPACE STATION AND A SATELLITE



 Lockheed

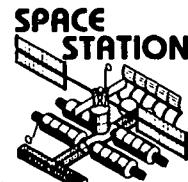
INTERVAL BETWEEN NODAL  
COINCIDENCES OF A 60-DEG. SPACE STATION AND SATELLITE

---

The time interval between successive nodal coincidences of orbits of a space station and a satellite is a function of the inclination and altitude of the space station and satellite. For a space station located at 220-nmi circular and 60-deg. inclination, contours of constant time between nodal coincidences are shown on the facing page.

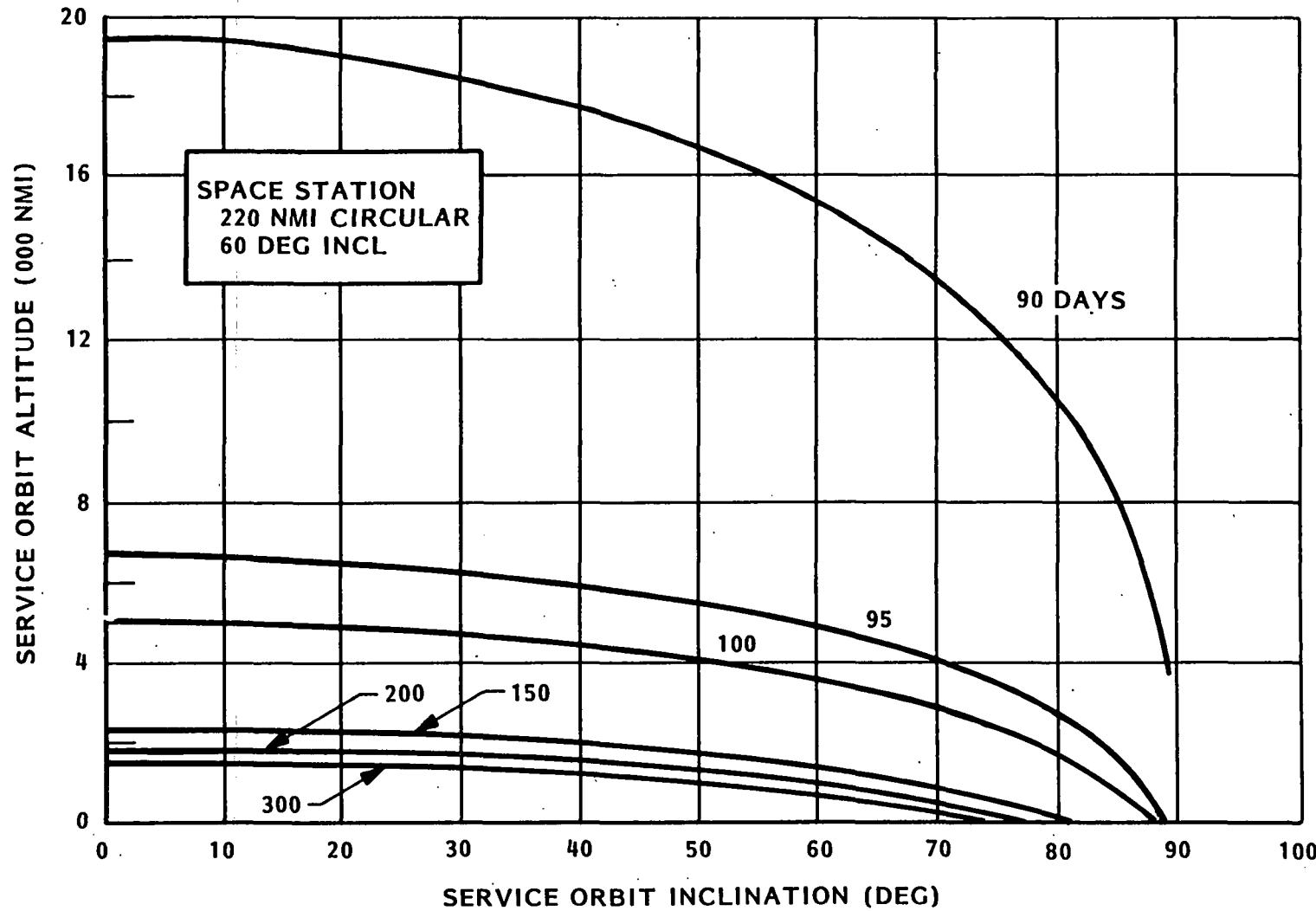
The minimum interval has increased significantly from 50 days for the 28.5-deg. station to 90 days for the 60-deg. station. More importantly the interval between nodal coincidence between the 60-deg. station and 60-deg. satellites at 600-nmi has increased to almost a year.





PROGRAMS

# INTERVAL BETWEEN NODAL COINCIDENCE OF A 60 DEG SPACE STATION AND SATELLITE



## IMPACT OF NON-OPTIMUM TIME OF LAUNCH FROM STATION

Consider a transfer vehicle capable of providing a roundtrip delta V of 20,000 ft/sec. This vehicle can make a roundtrip from the space station to satellites more than 7,000 miles in altitude at the same inclination and can make plane changes as much as 25-deg. (see figure on the facing page for zero days delay). All satellites within this initial volume can be reached at nodal coincidence.

The time available for minimum energy transfer is comparatively small. A delay of only 10 days after nodal coincidence increases the plane change requirements so that 20,000 ft/sec. is required to reach satellites at only 2,000 nmi altitude but 10 days beyond optimum position.

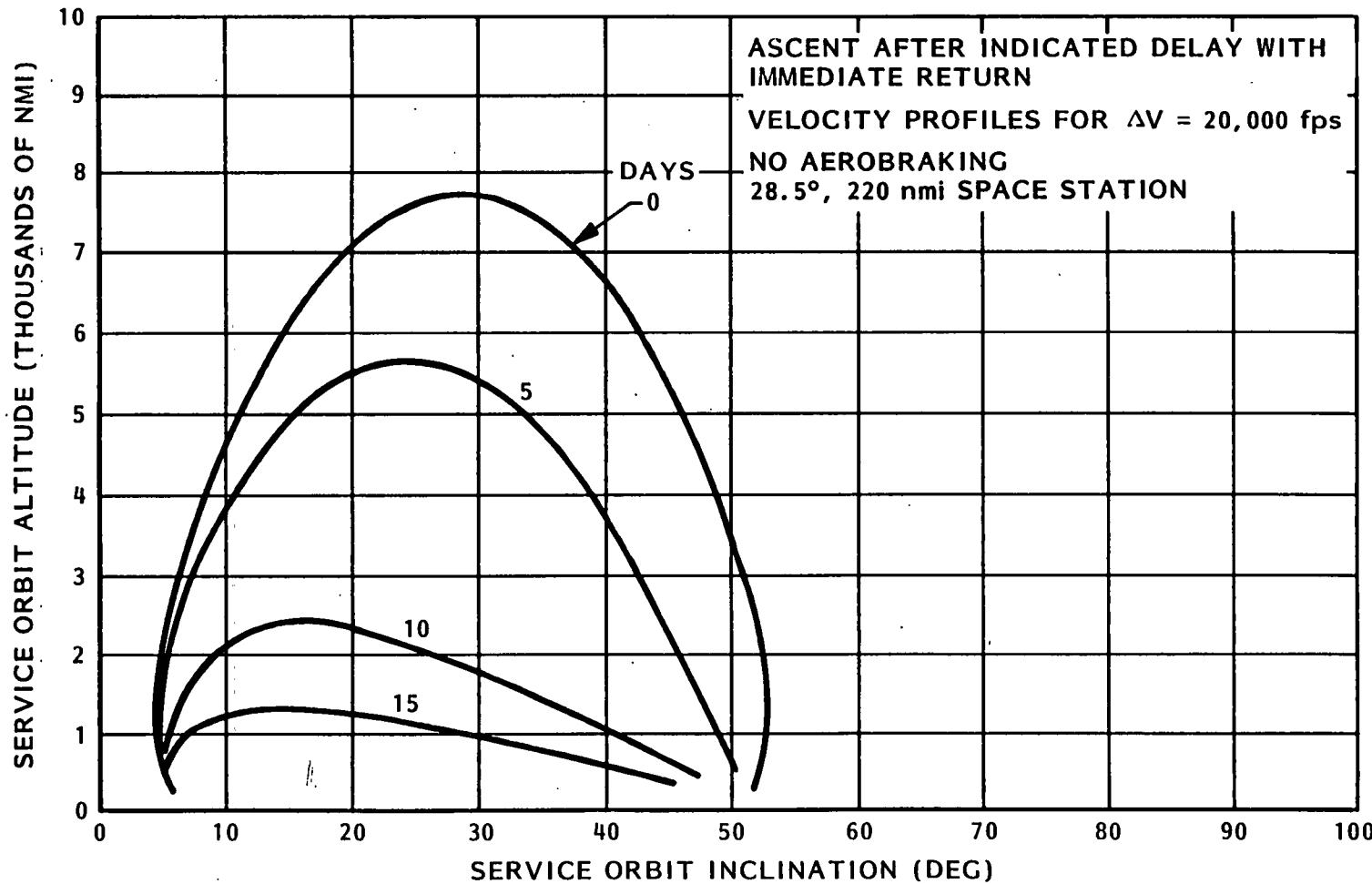
One consequence of this is that the time available to service a satellite on orbit is comparatively short. If a satellite is returned to the space station for repair and modification, the energy required to return it to its original orbit will be substantial unless the return to operational altitude is delayed until nodal coincidence. There are alternatives. One is to return the satellite to its operational altitude and inclination without placing it in the original plane. Such transfer could be made anytime. Large facilities such as the Space Telescope and the Advanced X-Ray Astronomical Facility could possibly use this latter mode. After repair and refurbishment, reboost to operational inclination and altitude could be done anytime if the specific orbit plane at a given inclination is not critical. Military satellites that are part of a constellation, such as the Global Positioning Satellite (GPS), on the other hand, must be returned to a specific plane as well as specific inclination and altitude. Phasing within the orbit plane is also critical. One way to solve that operational problem is to place a spare satellite on orbit when the operational satellite is taken out of service. After the deorbited operational satellite has been repaired or refurbished, it becomes the operational spare.

Although the details will vary, the character of the curve on the facing page will hold for any space station inclination between 28.5 and 70-deg. or more. Use of aerobraking does not alter the character of the curves, either. Equatorial (0-deg.) and polar (90-deg.) are special cases and must be addressed separately.



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## IMPACT OF LAUNCH FROM STATION AT NON-OPTIMUM TIME



LOCKHEED CORP.  
SACRAMENTO DIVISION

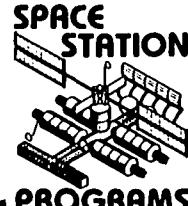
DELTA V FOR NON-OPTIMUM ORBIT TRANSFER

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The chart on the facing page shows the delta V required to make an orbit transfer anytime between a space station at 220-nmi circular orbit at 60-deg, and a satellite at 1,400-nmi in a circular orbit at 60-deg. The delta V required to transfer is computed using an optimized two-or three-burn maneuver with or without aerobraking. The roundtrip energy is substantially reduced if aerobraking is used on both ascent and return maneuver. The maximum apogee is limited to 50,000 miles for the three-burn maneuvers. Higher altitudes require slightly less energy, but with increased transit time. One-way transit time varies from approximately one hour for the region around nodal coincidence to a maximum of 35 hours in regions where the roundtrip delta V exceeds 25,000 ft/sec. The transit time is essentially the same with or without aerobraking. The effect of aerobraking depends on the specific transfer; however the upper limit is a maximum 7,000 ft/sec. benefit on both ascent and return.

A minimum energy roundtrip can be realized by making an immediate ascent (required, for instance, to place a spare satellite in operation), with the return flight made at nodal coincidence. The disadvantage is that the OTV and payload (if any) to be returned must wait several months on orbit before returning to the space station. An alternative mode is to immediately return to an operational altitude serviced by the Space Shuttle; the delta V required for that transfer is the same as a transfer to the station at nodal coincidence.



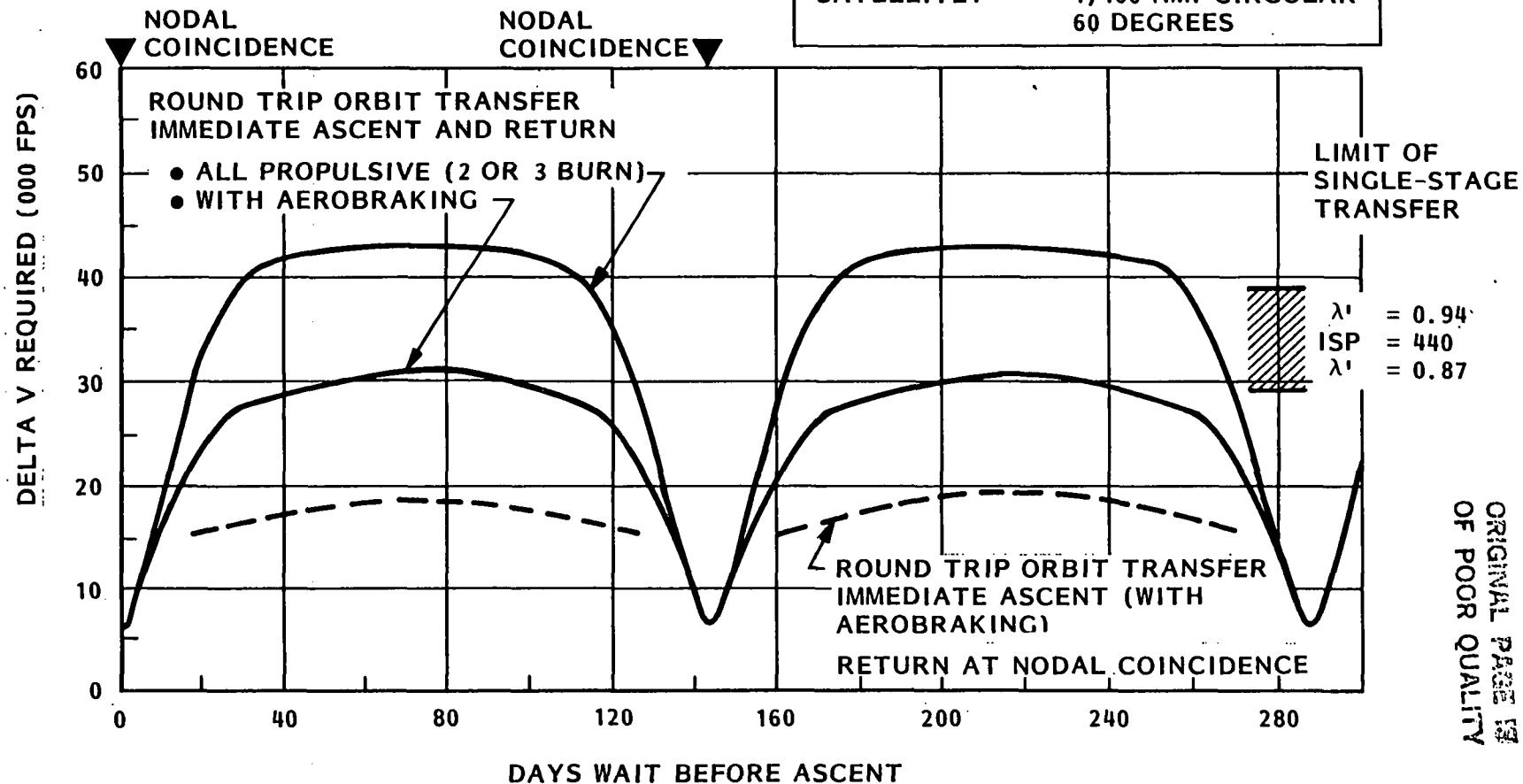


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## **DELTA V FOR TRANSFER AT NON-OPTIMUM TIME**

**SPACE STATION: 220 NMI CIRCULAR  
60 DEGREES**

**SATELLITE:** 1,400 NMI CIRCULAR  
60 DEGREES



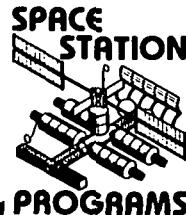
ORIGINAL PRINTS  
OF POOR QUALITY

PROPELLANT WEIGHT FOR IMPULSIVE TRANSFER

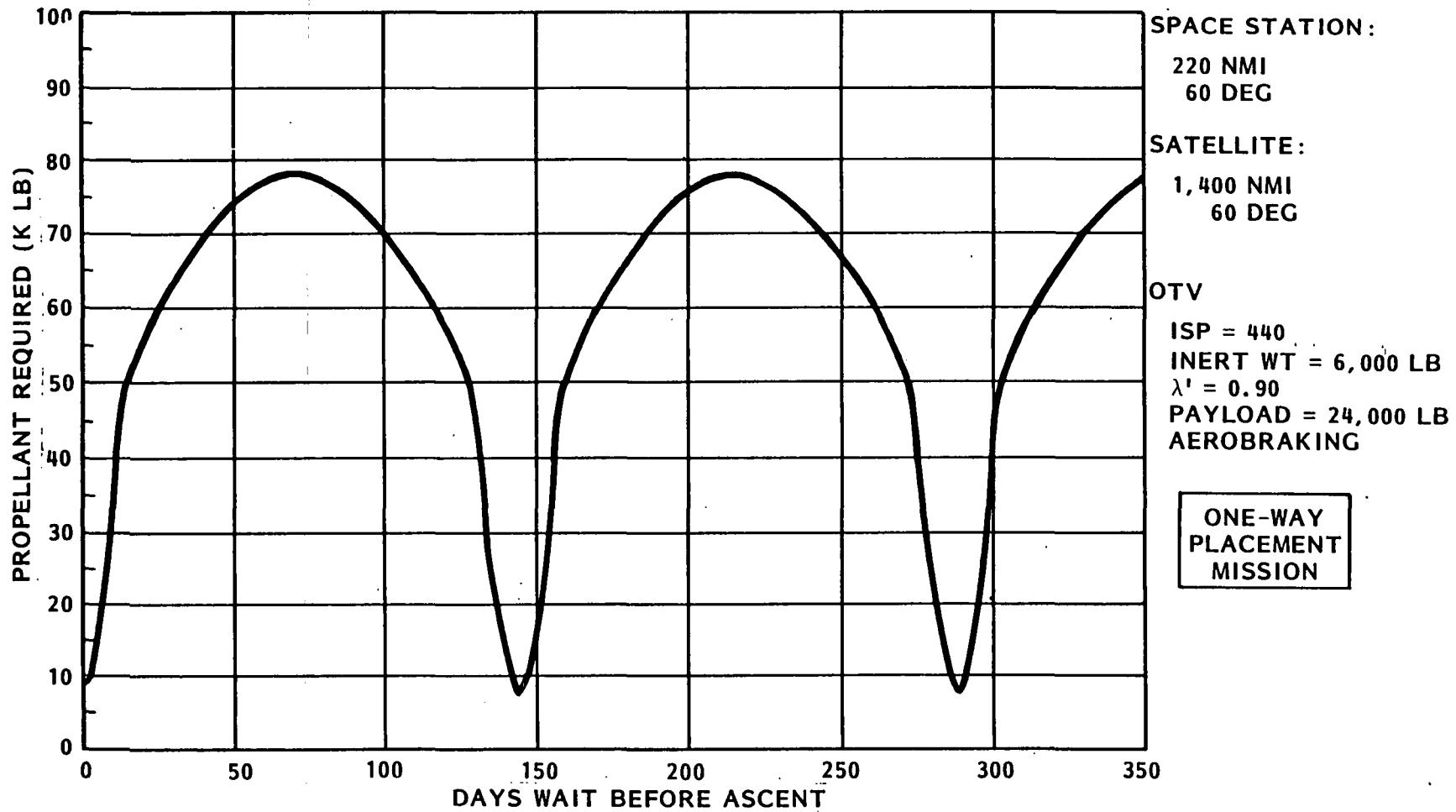
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The curves on the preceding page present the delta V required for roundtrip transfer. The peak delta V required for a one-way ascent transfer with aerobraking is approximately 16,000 ft/sec. The energy required at nodal coincidence for a one-way transfer is approximately 3,000 ft/sec. The data show propellant required for a cryogenic OTV with aerobraking capability. The payload is 24,000 lb., which is representative of a national security mission requirement. The data emphasize the substantial penalty that must be paid if a non-optimum transfer is made.





## PROPELLANT WEIGHT FOR ORBIT TRANSFER (24K LB PAYLOAD)



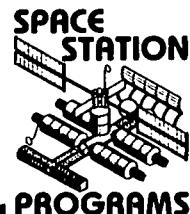
## PROPELLANT REQUIREMENTS FOR PLACEMENT AND RETURN MISSIONS AT NODAL COINCIDENCE

Routine maintenance of spacecraft can be scheduled years in advance and obviously planned to coincide with minimum energy transfer constraints. The preceding chart presented propellant requirements for a one-way placement mission. The data on the facing page show the propellant required for a roundtrip mission in which the OTV either ascends with a payload and returns empty (placement only), ascends empty and retrieves a satellite (return only), or ascends with a payload and returns with a comparable weight of payload (placement and return). The OTV model used in these calculations assumes no aerobraking and no inert weight penalty.. The data are given for both storable propellants ( $ISP = 300$ ) and cryogenic propellants ( $ISP = 440$ ).

Propellant requirements for these servicing missions are well within the capability of existing OTVs and thus these operations are well within existing capability. These propellant weights, combined with the spacecraft servicing model to establish frequency of potential servicing operations, have been used to determine a reasonable size for on-orbit propellant storage requirements.

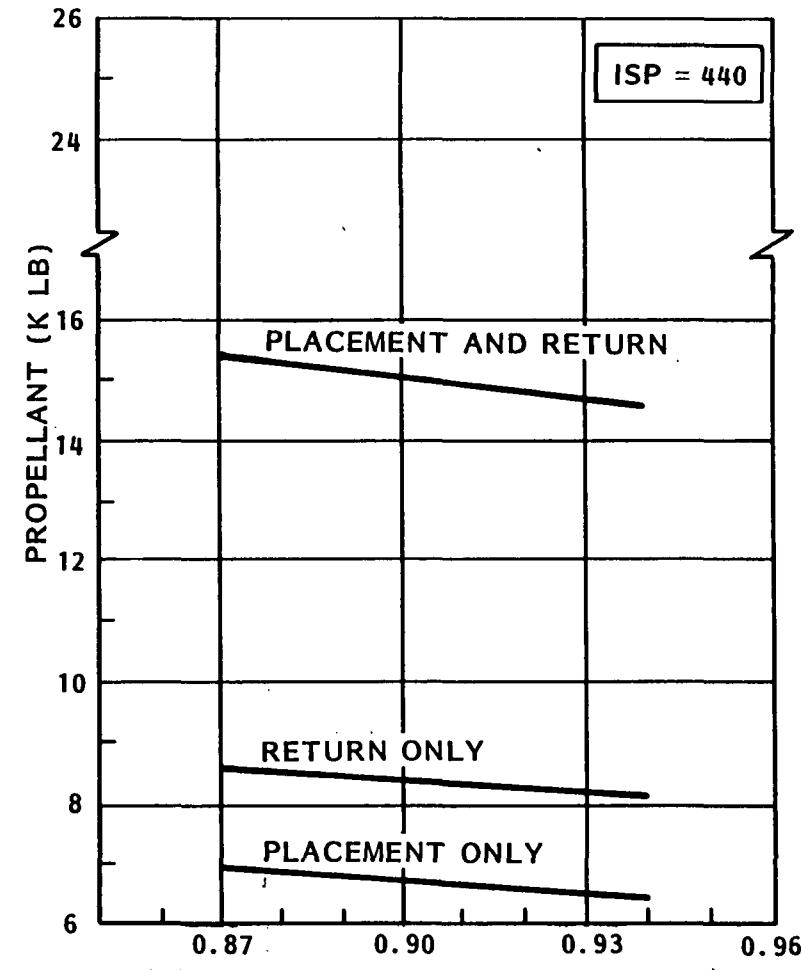
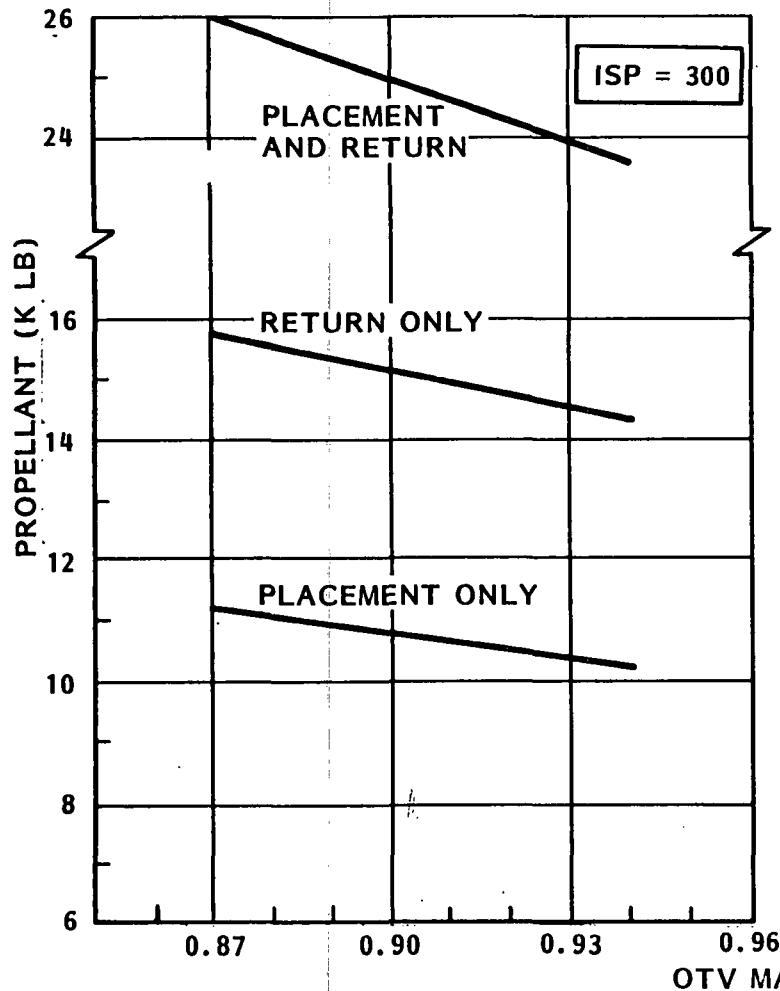
In the calculations for propellant requirements displayed here and on the preceding page, the space station and satellite to be serviced were both assumed to be at 60-deg. circular orbits. It was further assumed that orbit transfer is made at nodal coincidence. These two assumptions are significant since a modest change in either one would substantially affect propellant requirements (as pointed out previously). Routine servicing and maintenance of satellites can be performed from a space station if the satellites are reasonably close to the same inclination (detailed in subsequent pages).





## PROPELLANT REQUIREMENT

FROM 220 NMI TO 1,400 NMI (60 DEG CIRCULAR) - 24,000 LB PAYLOAD

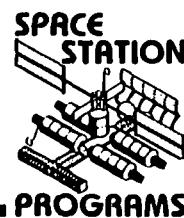


PROPELLANT REQUIREMENTS FOR PLACEMENT AND RETURN  
MISSIONS AT NODAL COINCIDENCE

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The data presented here are essentially identical to those presented on the preceding page, except the satellite to be serviced is at 600-nmi rather than 1,400-nmi. Propellant requirements are substantially lower and within the capability of the TMS.

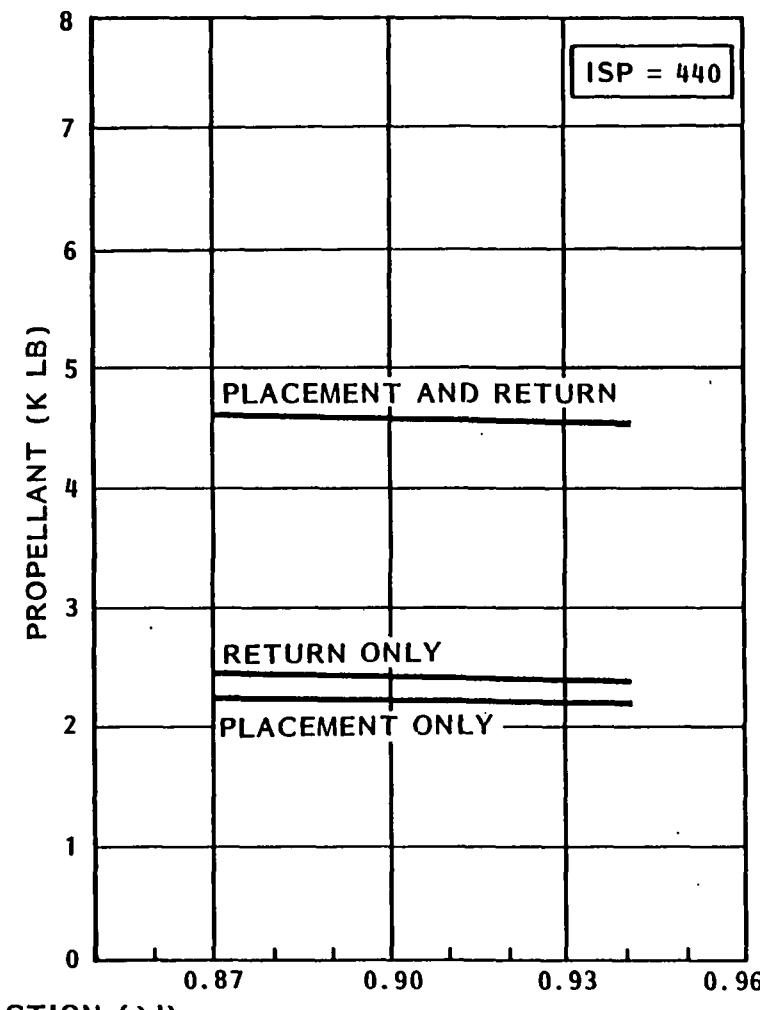
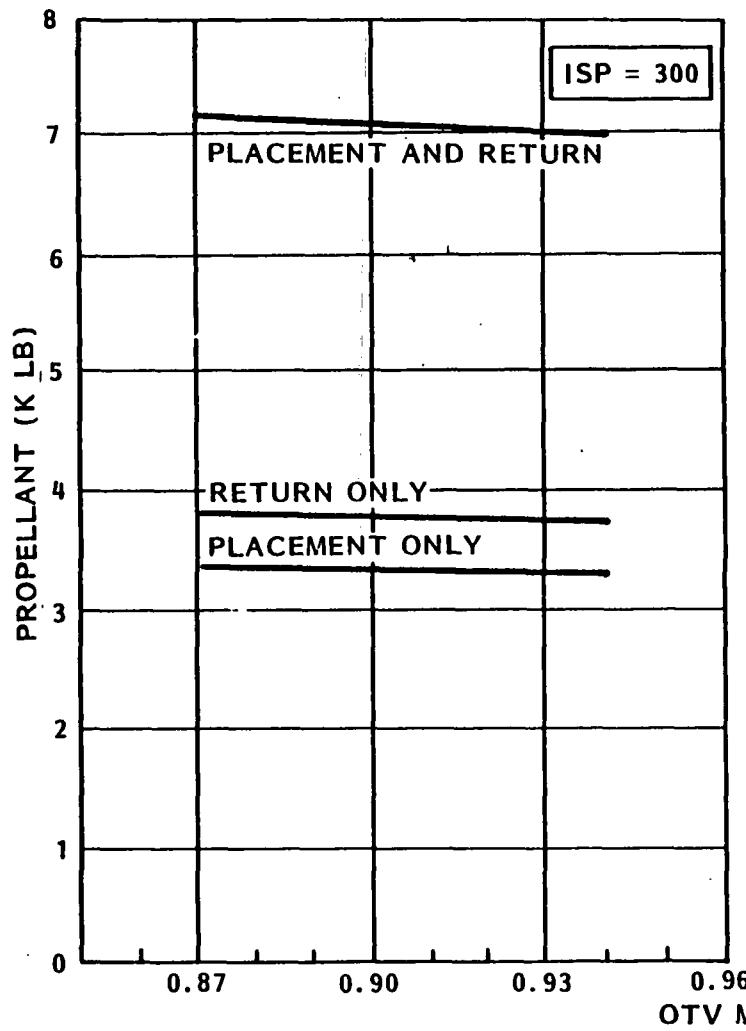




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## PROPELLANT REQUIREMENT

FROM 220 NMI TO 600 NMI (BOTH 60 DEG CIRCULAR) - 24,000 LB PAYLOAD



CATEGORY 3-SUMMARY  
SUPPORT OF SATELLITES IN NEARBY INCLINATION AT NODAL COINCIDENCE

---

The space station can be a cost-effective base for support to satellites at nodal coincidence in nearby inclinations. Even if we constrain orbit transfer to a delta V less than 15,000 ft/sec. for a round-trip transfer, the space station can provide a base to service satellites over 4,000 miles above it and up to 15 deg. inclination change. The constraint on the delta V keeps the transfer within the range where aerobraking is not beneficial. This simplifies the OTV configuration and allows us to use the Centaur and the proposed TMS.

Significant constraints are imposed by the limited time available for orbit operations at nodal coincidence and the relatively long period between nodal coincidences. Never the less, scheduled maintenance can be planned years in advance and represents a significant of potential business for the space station. In subsequent charts discussing space operation mission scenarios, it is shown that there is a substantial cost benefit to use of the space station rather than the Space Shuttle for servicing .





## CATEGORY 3 - SUMMARY SUPPORT OF SATELLITES IN NEARBY INCLINATION AT NODAL COINCIDENCE

ENERGY REQUIRED:  $\Delta V < 15,000$  FPS ROUND TRIP

REVISIT FREQUENCY: 60 TO 300 PLUS DAYS DEPENDING ON SATELLITE AND STATION  
INCLINATIONS AND ALTITUDES

OPERATIONS: SCHEDULED MAINTENANCE:

- EQUIPMENT CHANGEOUT
- PRODUCT OR EXPERIMENT SERVICING
- SPARES AND/OR FLUID RESUPPLY
- G&C UPDATE

WINDOW FOR SERVICING LIMITED TO FEW DAYS (IF  
SATELLITE IS TO REMAIN IN, OR BE RETURNED TO,  
ORIGINAL OPERATIONAL ORBIT)

OTV: CENTAUR TYPE - AEROBRAKING NOT REQUIRED, BUT IT  
SIGNIFICANTLY INCREASES ROUND TRIP CAPABILITY

SATELLITE LOCATION: INCLINATION  $\pm 15$  DEGREES FROM STATION INCLINATION  
ALTITUDE  $< 4000$  NM





## CATEGORY 4

### -UNIVERSAL SUPPORT OF LOW EARTH ORBIT (LEO) SATELLITES

- ONE-WAY ORBIT TRANSFER
- TYPICAL MISSIONS
  - ON ORBIT LAUNCH OF SPARE SATELLITE  
(e.g. ITSS SPACE-BASED RADAR)
  - SPACE SHUTTLE ORBITER CREW  
RESCUE VEHICLE

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1.5-65

## DELTA VELOCITY REQUIRED FOR ORBIT TRANSFER AT NON-OPTIMUM TIMES (WITHOUT AEROBRAKING)

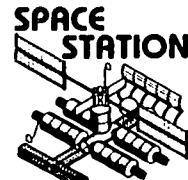
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In this section, we will examine more carefully the impact of orbit transfer at non-optimal times. A particular focus will be the influence of space station location on the energy required for orbit transfer.

Four sets of curves are presented in the figure on the facing page. The data for the delta V required to transfer from a station at 60-deg, 220-nmi, to a satellite at 60 deg, 1400-nmi are identical to the data shown earlier. The energy required to transfer to a 600-nmi satellite is also shown; interestingly, although the energy at nodal coincidence is significantly lower, the maximum energy for orbit transfer at non-optimum time is essentially the same, independent of spacecraft altitude. Also, if the space station were at 28.5-deg the energy required for orbit transfer to the 60-deg satellite location at nodal coincidence is substantially increased but the energy required for transfer at a non-optimum time is not significantly different, and, in fact, is lower than the peak energy required from the 60 deg station.

Note that these non-optimal transfers use a three burn trajectory with the intermediate apogee set not to exceed 50,000-nmi. No aerobraking was used in determining these roundtrip delta V requirements.



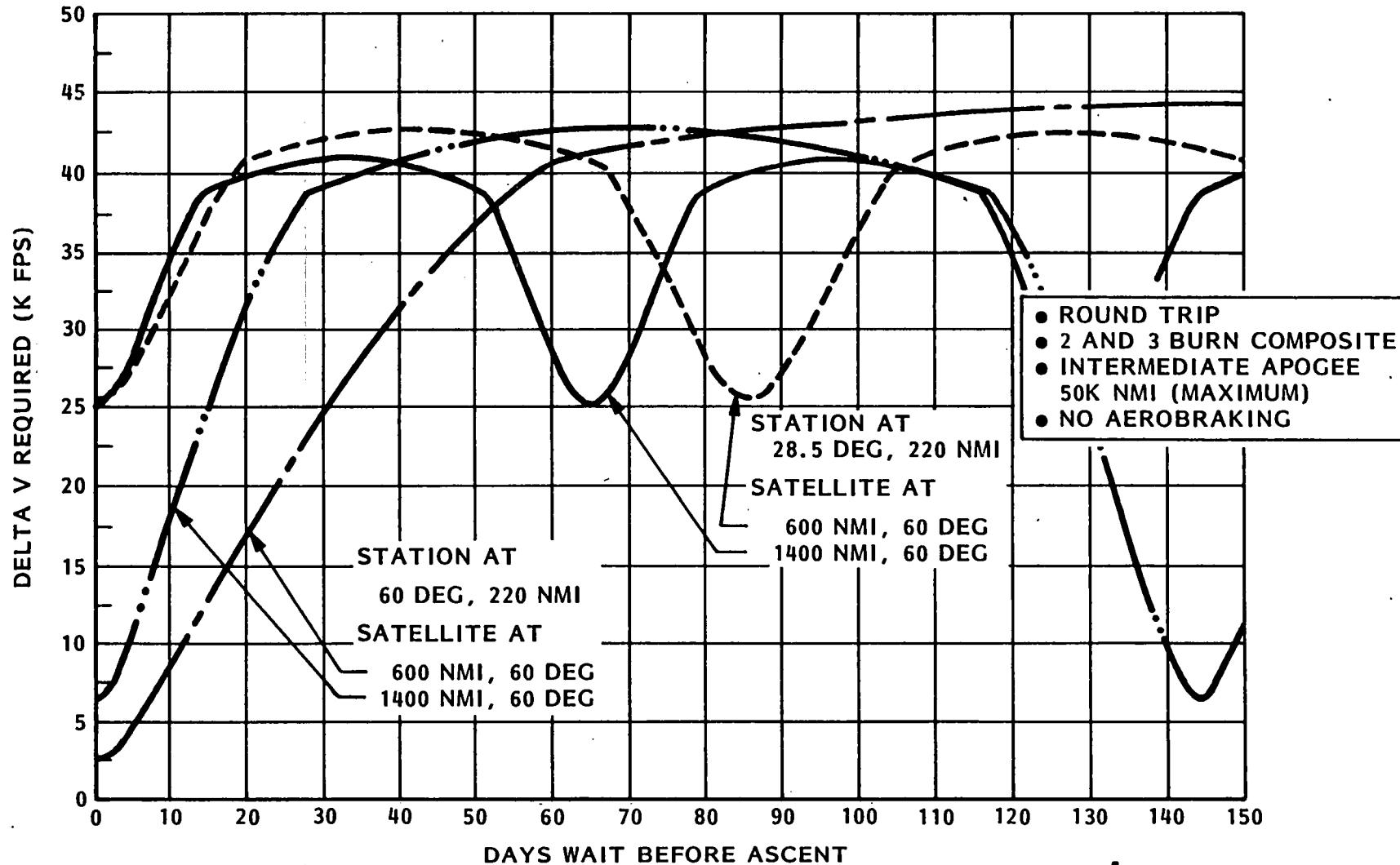


PROGRAMS

LMSC-D889718

## ΔV FOR TRANSFER AT NON-OPTIMUM TIMES

(NO AEROBRAKING)

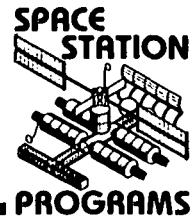


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DELTA V REQUIRED FOR ORBIT TRANSFER AT  
NON-OPTIMUM TIMES  
(WITH AEROBRAKING)

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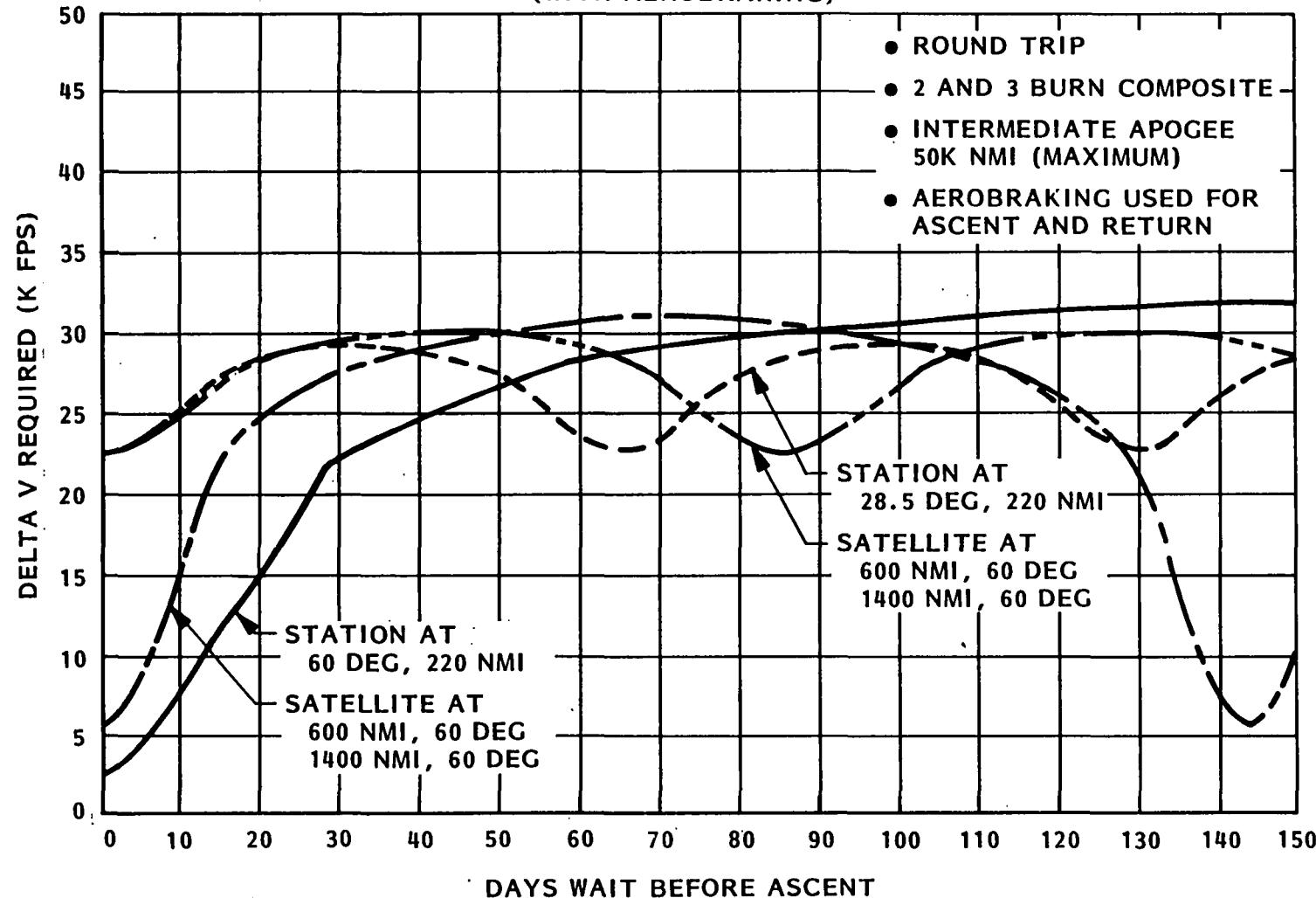
These data are identical to those presented on the preceding page, except the effect of aerobraking is included. Note that the minima at nodal coincidence for a 60° station are unaffected by aerobraking. Also, the maxima are reduced substantially and the spread between maxima for the various cases is reduced significantly. These data suggest that the limitation on space station location is critical for minimum energy transfers but is not significant for non-optimal transfer. This is explored further in the following pages.



LMSC-D889718

## ΔV FOR TRANSFER AT NON-OPTIMUM TIMES

(WITH AEROBRAKING)



INFLUENCE OF STATION INCLINATION ON  
DELTA V FOR ONE-WAY TRANSFER - CASES 1 AND 2

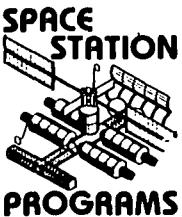
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To determine the influence of station inclination on delta V required for minimum energy transfer at non-optimum times, a series of cases was examined. Space station location and time of transfer (in terms of delay after nodal coincidence) were varied while the satellite location remained at 1,400-nmi, 60-deg. inclination. The one-way delta V was computed for designs with and without aerobraking (cases 1 and 2).

As shown, the minima follow a regular pattern, creating valleys in the surface. The most significant fact is that the maxima in case 1 (no aerobraking) are generally bounded by a 20,000 ft/sec. upper bound regardless of station inclination. The behavior for case 2 (with aerobraking) is essentially the same except that the upper bound is about 15,000 ft/sec.

The heavy line on this and the subsequent figures emphasizes the delta V required to make the transfer from a station in the same inclination as the satellite.

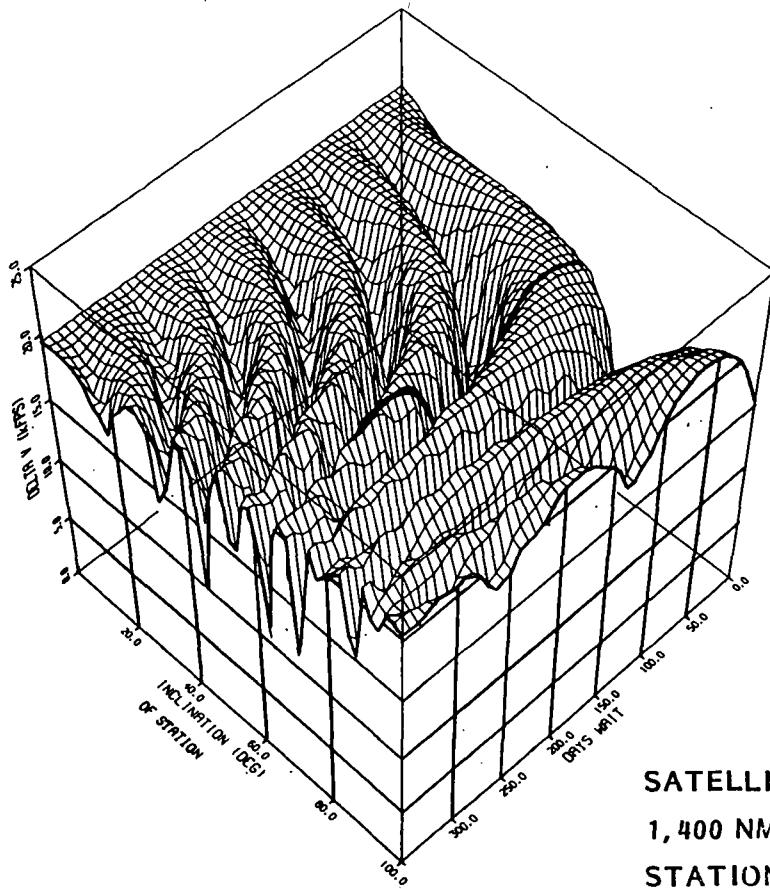




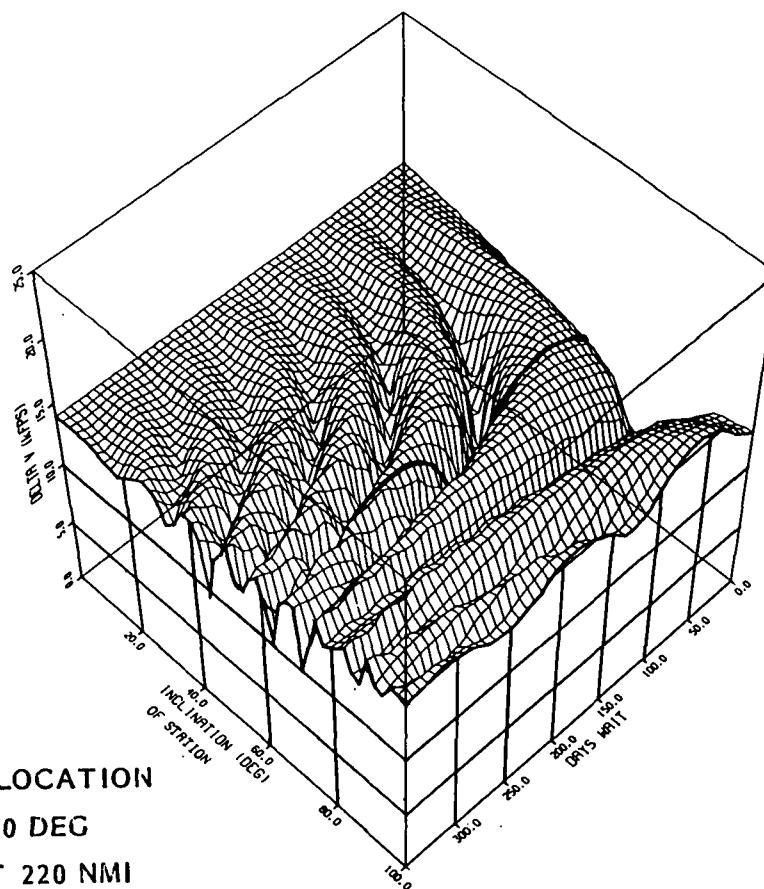
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## INFLUENCE OF STATION INCLINATION ON $\Delta V$

ONE WAY TRANSFER - CASE 1



ONE WAY TRANSFER - CASE 2



SATELLITE LOCATION  
1,400 NMI, 60 DEG  
STATION AT 220 NMI  
NO AEROBRAKING

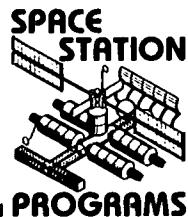
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INFLUENCE OF STATION INCLINATION ON  
DELTA V FOR ONE-WAY TRANSFER - CASES 3 AND 4

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The objective here is to examine the influence of changing satellite location. In the preceding two cases, the satellite was at 60 deg., whereas in this case the satellite is at 28.5 deg. Its altitude remains unchanged at 1,400-nmi. The energy required to reach this satellite from low-inclination space stations is significantly less than that required to reach the satellite from higher inclination orbits. Significantly, however, the surface is bounded by a maximum limit of about 20,000 ft/sec for systems without aerobraking, and about 15,000 ft/sec for systems with aerobraking, just as in cases 1 and 2.

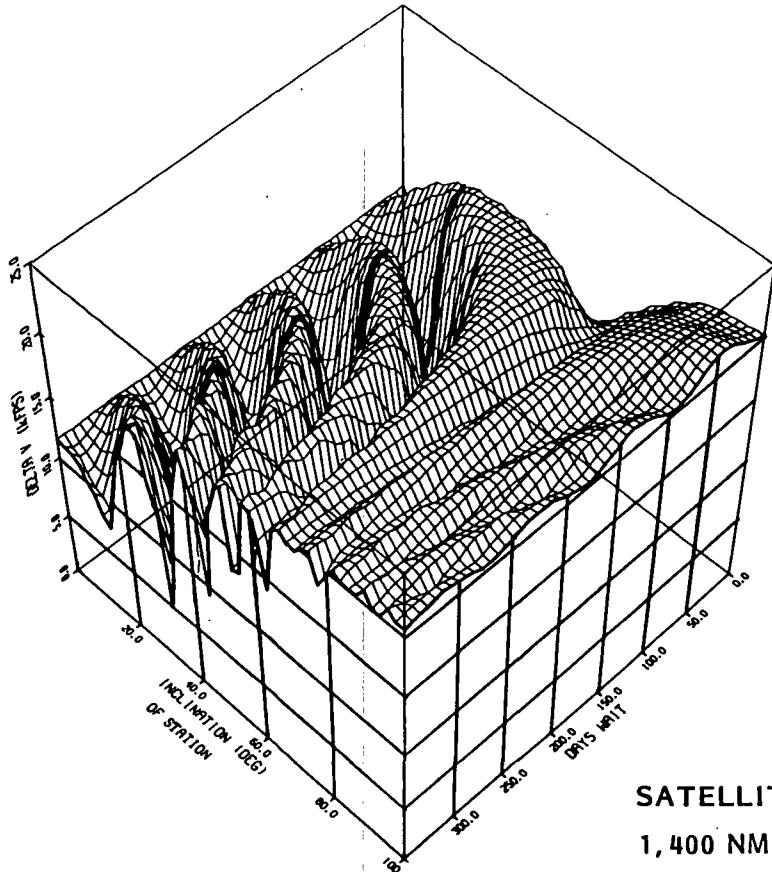




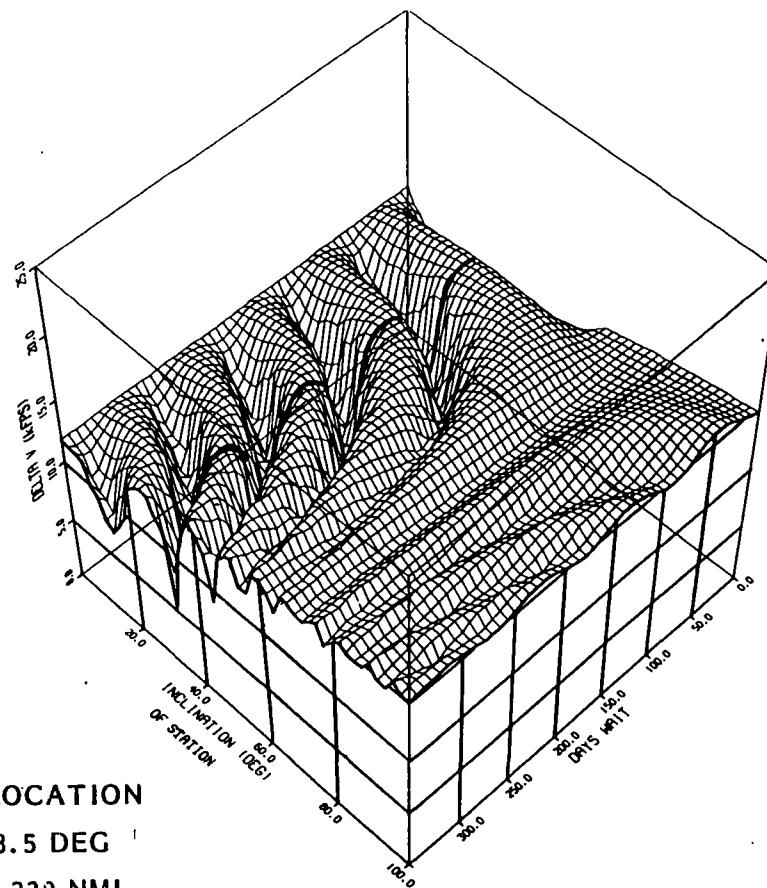
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## INFLUENCE OF STATION INCLINATION ON $\Delta V$

ONE WAY TRANSFER - CASE 3



ONE WAY TRANSFER - CASE 4



SATELLITE LOCATION  
1,400 NMI, 28.5 DEG  
STATION AT 220 NMI  
WITH AEROBRAKING

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INFLUENCE OF STATION INCLINATION ON  
DELTA V FOR ONE-WAY TRANSFER - CASE 5 AND 6

---

To examine the influence of satellite altitude on the required transfer energy, we now consider a series of cases in which the satellite is at 600-nmi. In this case, the satellite is at 60-deg. and the data are presented for the configuration without aerobraking. The surface is bounded once again by a maxima of about 20,000 ft/sec without aerobraking or 15,000 ft/sec with aerobraking. There is an interesting trough at about 68-deg. in which the minima appear to be independent of days after nodal coincidence. The significance of this feature has not been investigated.

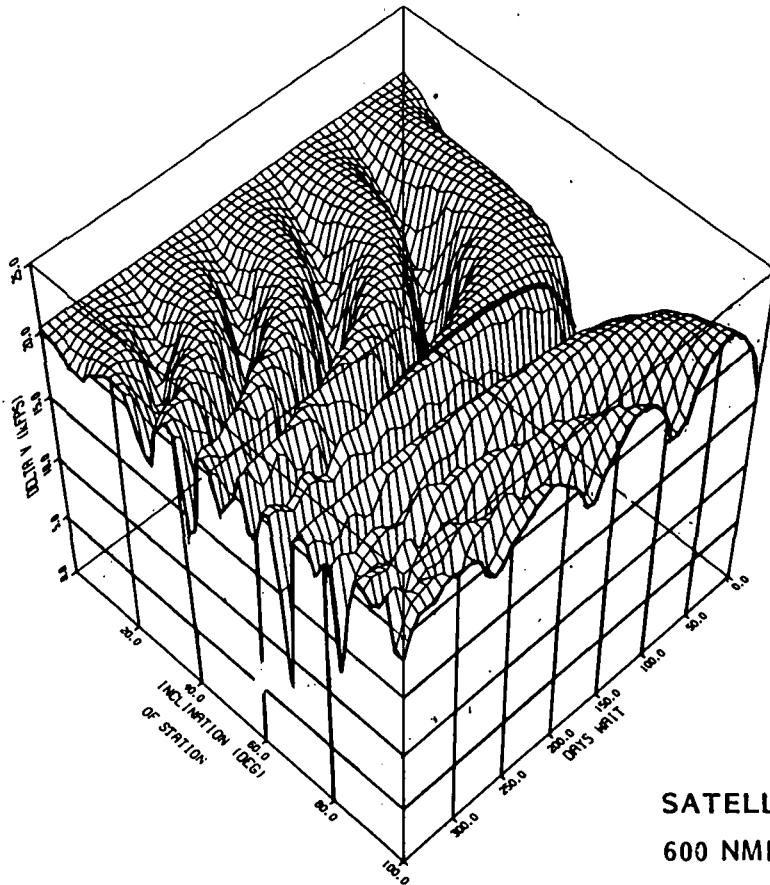




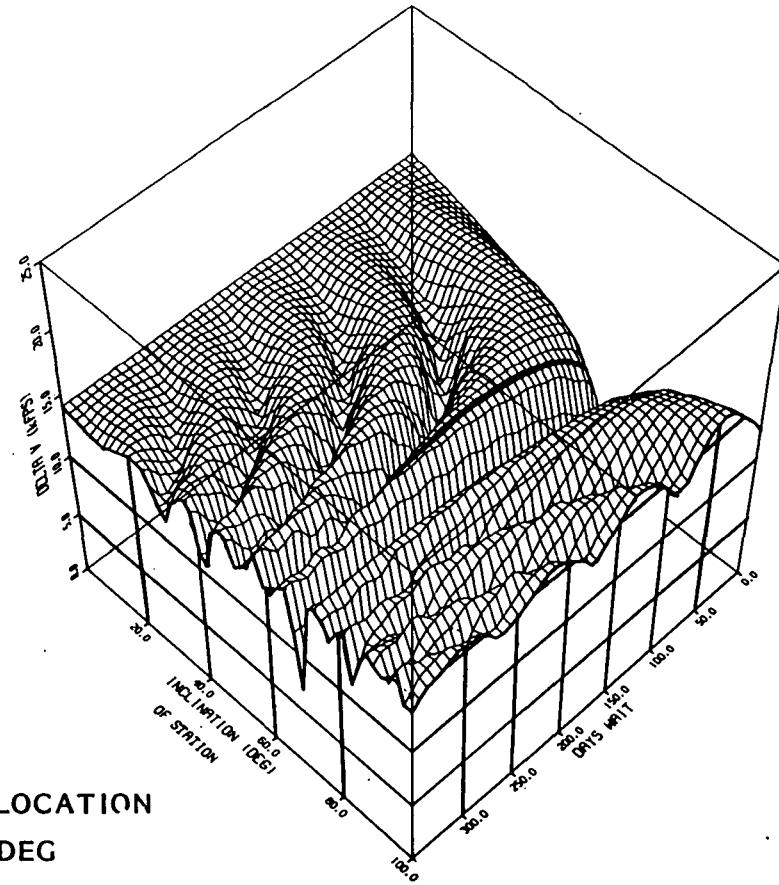
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## INFLUENCE OF STATION INCLINATION ON $\Delta V$

ONE WAY TRANSFER - CASE 5



ONE WAY TRANSFER - CASE 6



SATELLITE LOCATION  
600 NMI, 60 DEG  
STATION AT 220 NMI  
NO AEROBRAKING

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INFLUENCE OF STATION INCLINATION ON  
DELTA V FOR ONE-WAY TRANSFER - CASES 7 AND 8

---

In direct parallel with case 3, the satellite inclination was changed to 28.5-deg., while the altitude is kept constant at 600-nmi. Again, as with cases 3 and 4, the delta V required to reach a satellite with low inclination stations is considerably less than the delta V to reach it from higher inclination stations, but the maxima are bounded by approximately 20,000 ft/sec without aerobraking and 15,000 ft/sec with. Note that the trough of minima, relatively independent of the days after nodal coincidence, still appears in the surface but it has moved to approximately 50-deg. Again, the significance, if any, of this phenomenon was not examined.

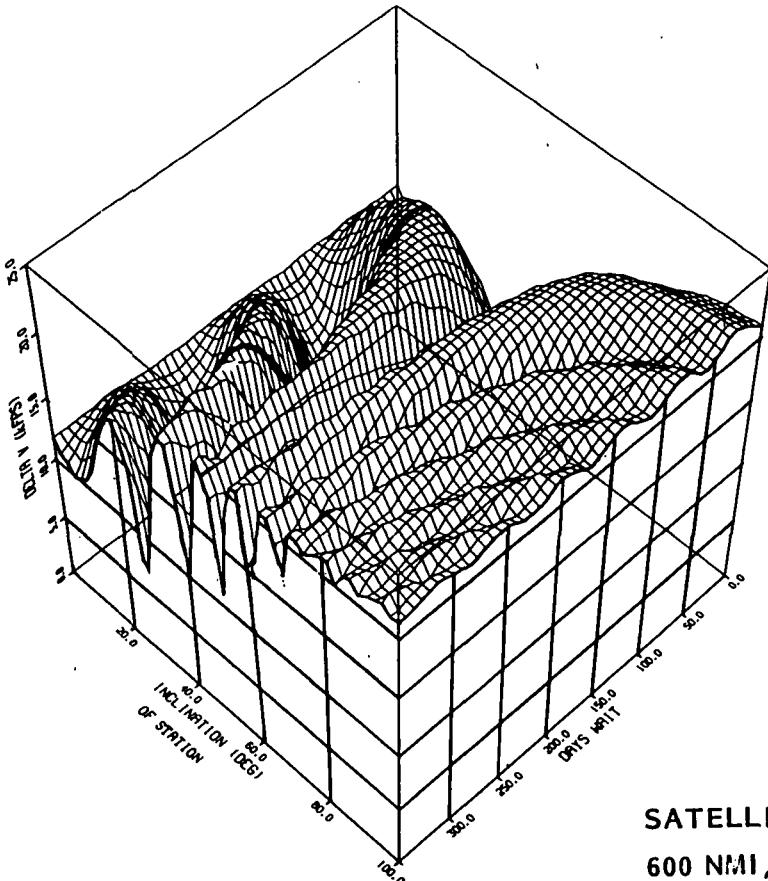




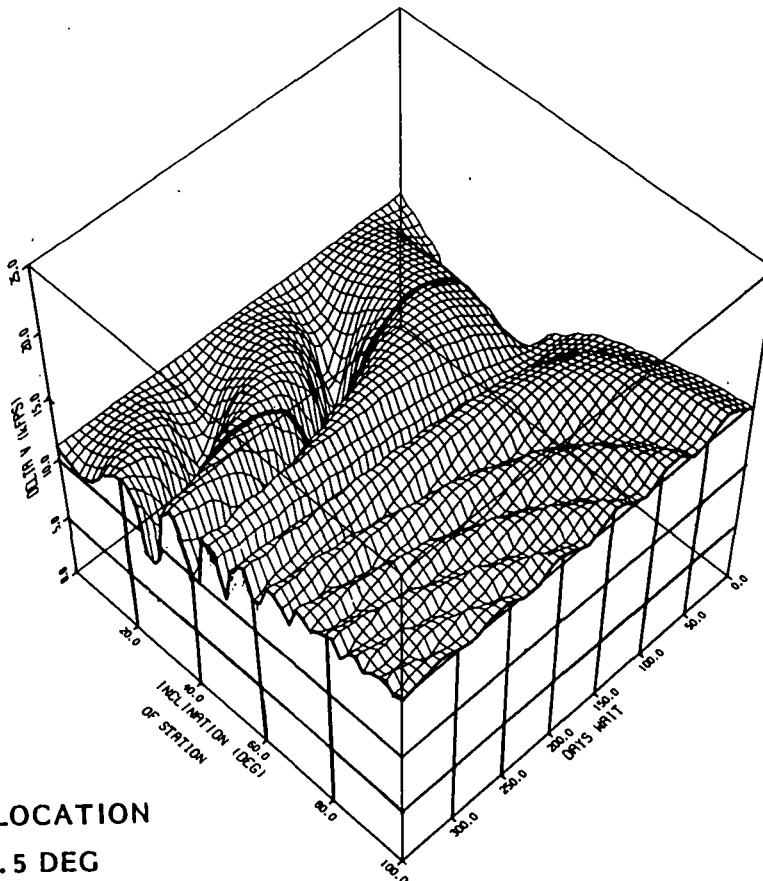
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## INFLUENCE OF STATION INCLINATION ON $\Delta V$

ONE WAY TRANSFER - CASE 7



ONE WAY TRANSFER - CASE 8



SATELLITE LOCATION  
600 NMI, 28.5 DEG  
STATION AT 220 NMI  
NO AEROBRAKING

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CATEGORY 4-SUMMARY  
UNIVERAL SUPPORT OF LEO SATELLITES

---

The eight cases examined on the preceding pages are significant because they highlight the fact that, for minimum energy transfer at non-optimum times, the location at the space station has only a small influence on total transfer energy. Also, aerobraking has a profound affect in reducing the energy required for these non-optimum transfers.

There are several of important missions that require such immediate response. An example is the rescue of a Shuttle orbiter crew. Another is replacing an operational satellite that has failed and when there is a time-critical need to replace the failed satellite. These scenarios are explored further in subsequent sections.



## CATEGORY 4 - SUMMARY UNIVERSAL SUPPORT OF LOW EARTH ORBIT (LEO) SATELLITES

ENERGY REQUIRED:       $\Delta V < 23,000$  FPS - NO AEROBRAKING  
                                 $\Delta V < 17,000$  FPS - WITH AEROBRAKING  
                                (FOR ONE-WAY TRANSFER)\*

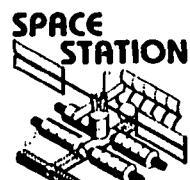
REVISIT FREQUENCY:      UNLIMITED (TRANSFER TIME VARIES FROM  
                                1 HOUR TO 35 HOURS, DEPENDING ON SATELLITE  
                                AND STATION LOCATIONS)

OPERATIONS:      PRIMARILY USEFUL WHEN SHORT RESPONSE TIME  
                                IS REQUIRED: SHUTTLE-BASED SERVICING WILL  
                                BE COMPETITIVE IN OTHER CASES

OTV:      WIDE-BODE CENTAUR TYPE - WITH ADDITION OF  
                                AEROBRAKING

SATELLITE LOCATION:      UNLIMITED

\*PROPELLANT STORED AT KEY ORBITS (E.G. 28.5°, 60°, 98°) COULD ALLOW AUTOMATED  
REFUELING OF OTV FOR RETURN FLIGHT



PROGRAMS

## CATEGORY 5

### -UNIVERSAL SUPPORT OF GEOSYNCHRONOUS EARTH ORBIT (GEO) SATELLITES

- PLACEMENT OF LARGE SATELLITES
- REFUELING
- AUTOMATED CHANGEOUT
- MANNED MISSIONS

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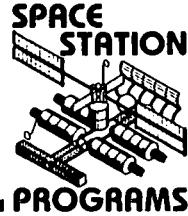
DELTA V FOR IMPULSIVE TRANSFER TO 0-DEG. GEO SATELLITE

---

One potential servicing mission for a space-station-based OTV is one-way support of GEO satellites. First, we will consider GEO satellites at 0-deg. inclination. Since there is no nodal drift between the station and a 0-deg. inclination satellite, a two-dimensional plot of required delta V versus station inclination is adequate to define the effect of station inclination on transfer energy. Time (days wait before ascent) is not a factor in this instance. As shown on the facing page, the minimum energy transfer is made with a three-burn trajectory but without aerobraking. Since the terminal altitude is so high (19,323-nmi) an aerobraking trajectory (with a constrained maximum apogee of 50,000-nmi) on the ascent maneuver is of no benefit. Aerobraking will reduce the energy required on the return trajectory.

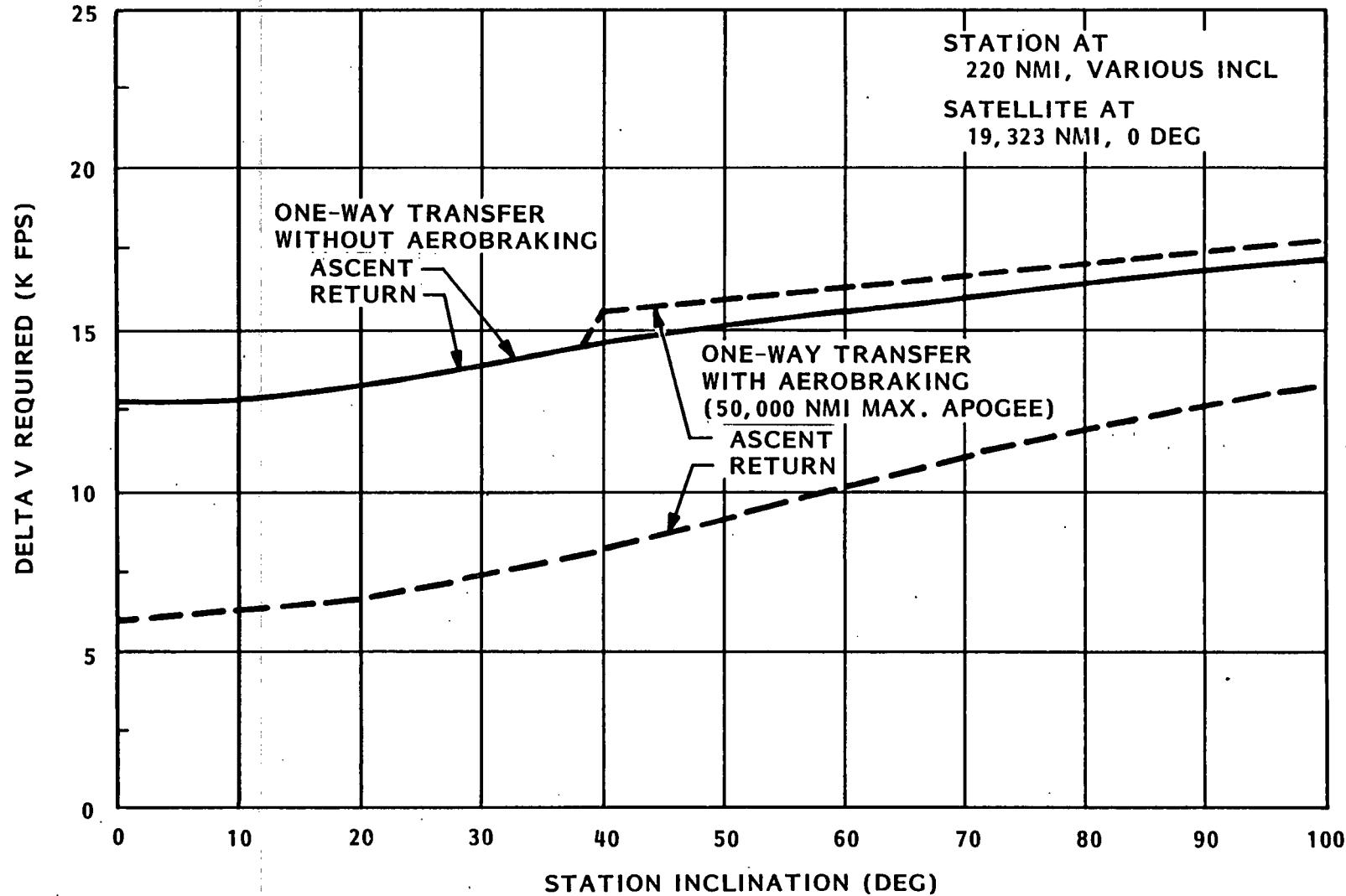
As shown in the graph, there is an effect of station location on the delta V required for the transfer to GEO. However, the basic energy requirement is close to 15,000 ft/sec., which is similar to the energy required to reach an LEO satellite at non-optimum times. Transfers at this level are clearly within the capability of existing spacecraft such as the Centaur or the IUS. The propellant required to make the transfer or, conversely, the payload limitations of existing OTVs, can be determined from the data on pages OP-15 and OP-16.





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## DELTA V FOR TRANSFER TO 0 DEG GEOSYNCHRONOUS EARTH ORBIT SATELLITE



TRANSFER TO 65-DEG. GEO FROM VARIOUS STATION INCLINATIONS

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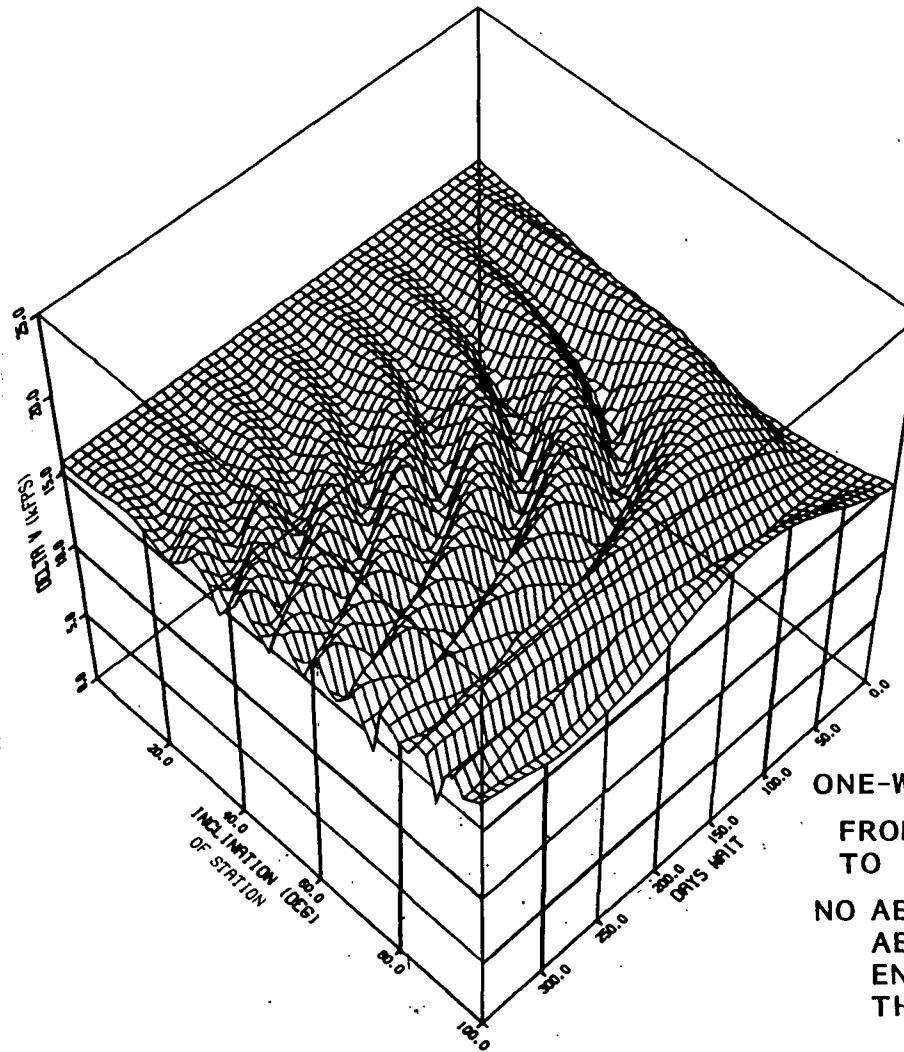
There is relative nodal drift between the GEO satellite at 65-deg. and the space station at 220-nmi. Thus, a three-dimensional representation is again the easiest way to examine the influence of space station inclination on energy required to transfer to GEO. As in the preceding case, aerobraking maneuvers on ascent from LEO to 19,323-nmi actually increase the energy required. Aerobraking on reentry would save energy since the terminal altitude is in LEO. As shown in the figure, a variation in delta V is required as a function of time, but the entire surface is bounded by a maximum energy from 15,000 ft/sec. to 17,000 ft/sec.





LMSC-D889718

## TRANSFER TO A 65 DEG GEO SATELLITE FROM VARIOUS STATION INCLINATIONS



ONE-WAY (ASCENT) TRANSFER  
FROM 220 NMI  
TO 65 DEG ORBIT AT 19,323 NMI  
NO AEROBRAKING (USE OF  
AEROBRAKING INCREASES  
ENERGY REQUIRED FOR  
THIS SET OF PARAMETERS)

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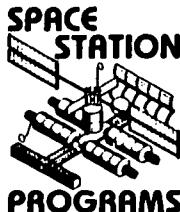
CATEGORY 5-SUMMARY  
UNIVERSAL SUPPORT OF GEO SATELLITE

---

The energy required to reach GEO is comparable to that required to reach LEO orbits at non-optimum time. One significant difference is that aerobraking is not of value on GEO ascent missions, while aerobraking has a substantial effect in reducing energy required for LEO transfers. The energy required to reach GEO is not radically affected by space station orbit inclination, although there is a significant difference in delta V required for a GEO transfer from a 90-deg. station compared to a zero-degree station.

Orbit transfer to GEO is obviously within the capability of existing OTVs. Using a pair of OTVs in tandem can increase the payload capability significantly, thus allowing use of existing OTVs for space-based operations. Clearly, space operations can be performed from a space station without building a new OTV.





## CATEGORY 5 - SUMMARY UNIVERSAL SUPPORT OF GEOSTATIONARY EARTH ORBIT (GEO) SATELLITES

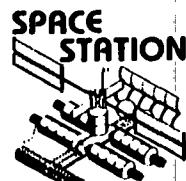
ENERGY REQUIRED:                   ASCENT  
   $\Delta V$  ~ 13K TO 17K FPS - AEROBRAKING NOT BENEFICIAL  
  RETURN  
   $\Delta V$  ~ 6K TO 13K FPS - WITH AEROBRAKING

REVISIT FREQUENCY:                 UNLIMITED (TRANSFER TIME APPROXIMATELY 35 HOURS)

OPERATIONS:                         ONEWAY PLACEMENT, AUTOMATED REFUELING AND EQUIPMENT  
  CHANGEOUT  
  ROUNDRIP SATELLITE RETURN AND MANNED MISSIONS ARE SECOND  
  GENERATION

OTV:                                 WIDE-BODY CENTAUR TYPE, IN TANDEM IF REQUIRED, PROVIDES AN  
  "EXISTING" CAPABILITY

SATELLITE LOCATION:                 UNLIMITED



PROGRAMS

## CONCLUSIONS

### CONSTRAINTS ON SPACE-BASED OPERATIONS IMPOSED BY ORBIT MECHANICS

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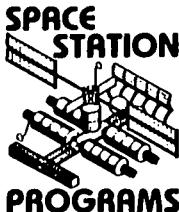
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CONCLUSIONS  
CONSTRAINTS ON SPACE OPERATIONS DUE TO ORBITAL MECHANICS

---

The space station is clearly suitable as a base for space operations, possibly one of the most important functions of a station. For a specific mission, space-station-based and Shuttle-based support should be compared. As shown on the facing page, the station is the better choice for a broad class of satellites. The station offers a unique capability for support to any LEO orbit, but the energy required is substantial even for one-way missions. Thus, station-based missions in this category should be restricted to critical activities that warrant the energy expenditure. Several significant missions meet these criteria. In fact, these missions are so important that they are a key element in providing justification to proceed with the initial phase of the space station.





## CONCLUSIONS

SPACE STATION PROVIDES POWERFUL CAPABILITY FOR SPACE-BASED OPERATIONS

UNDERSTANDING OF ORBITAL MECHANICS CONSTRAINTS IS ESSENTIAL FOR PROPER MISSION PLANNING

STATION IS BETTER THAN SHUTTLE FOR SUPPORTING SCHEDULED SERVICING, MAINTENANCE, AND RESUPPLY OF:

- PAYLOADS AND SATELLITES IN STATION TRACKING ORBITS
- SATELLITES IN NEARBY INCLINATIONS AT NODAL COINCIDENCE; TO SERVICE MAJORITY OF SATELLITES, REQUIRE STATIONS AT 28.5°, 60°, 90°
- GEO SATELLITES (STATION LOCATION NOT STRONG DRIVER)

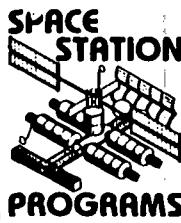
SHUTTLE IS PROBABLY BETTER THAN STATION FOR:

- SERVICING SATELLITES AT NON-OPTIMUM TIMES
- EMERGENCY RESUPPLY

STATION OFFERS UNIQUE CAPABILITY INDEPENDENT OF STATION OR SATELLITE LOCATION FOR:

- RECONSTITUTION VIA SPACE-BASED LAUNCH
- SHUTTLE CREW RESCUE

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# MISSION SCENARIOS FOR SPACE OPERATIONS

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1.5-93

SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

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The mission scenarios were selected to be representative of the five categories of space operations. The astronomy platform is included in two categories to define the differences (if any) between a tethered platform and free flyers, from the mission user point of view.

Each mission was discussed with users for each area. Generally, space-based operations is viewed as one of the primary purposes of the space station and users philosophically endorse these mission descriptions on that basis. Of the mission scenarios, however, only Space Telescope is far enough along to provide solid endorsement. The ITSS space-based radar satellite study was performed in sufficient depth to provide the basis for good cost projections comparing Shuttle-based servicing with station-based servicing (station-based servicing has significant cost advantages, as shown later). However, results of the LMSC ITSS study show that satellite servicing is not cost effective since the study groundrules were that the vehicle had to carry onboard propellant for return to the Shuttle for servicing. This is a reasonable requirement for programs planned for operation in 1985 to 1990; however, it must be reexamined for systems to be operational in the mid-1990s.

Space-station-based support assumes that the station is in the proper inclination. Thus, one station at 28.5-deg. could support six of the seven missions (the astronomy platform is counted only once); a station at 60-deg. is required to support space-based radar maintenance.



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## SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

THESE MISSION SCENARIOS HAVE BEEN SELECTED TO COVER THE FIVE CATEGORIES OF SPACE OPERATIONS

### ON-BOARD OPERATIONS

- 1- HARD DOCKED PAYLOADS, CAPTIVE FREE-FLYER, AND TETHERED SATELLITES
  - 0      LARGE STRUCTURES ASSEMBLY (LARGE ANTENNA FOR SPACE RADAR)
  - 0      ASTRONOMY PLATFORM SUPPORT (TETHERED)

### REMOTE OPERATIONS

- 2- SUPPORT OF SATELLITES IN LOCAL STATION VICINITY
  - 0      ASTRONOMY PLATFORM SUPPORT (AS A FREE-FLYER)
- 3- SUPPORT OF SATELLITES IN NEARBY INCLINATIONS AT NODAL COINCIDENCE
  - 0      SPACE TELESCOPE MAINTENANCE
  - 0      SPACE BASED RADAR (ITSS) MAINTENANCE
- 4- UNIVERSAL SUPPORT OF LEO SATELLITES
  - 0      PROMPT SATELLITE REPLACEMENT
  - 0      SHUTTLE CREW RESCUE VEHICLE
- 5- UNIVERSAL SUPPORT OF GEO SATELLITES
  - 0      GEO SATELLITE RESUPPLY





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## SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

THESE MISSION SCENARIOS HAVE BEEN SELECTED TO COVER THE FIVE CATEGORIES OF SPACE OPERATIONS

### ON-BOARD OPERATIONS

- 1- HARD DOCKED PAYLOADS, CAPTIVE FREE-FLYER, AND TETHERED SATELLITES
  - 0    LARGE STRUCTURES ASSEMBLY (LARGE ANTENNA FOR SPACE RADAR)
  - 0    ASTRONOMY PLATFORM SUPPORT (TETHERED)

### REMOTE OPERATIONS

- 2- SUPPORT OF SATELLITES IN LOCAL STATION VICINITY
  - 0    ASTRONOMY PLATFORM SUPPORT (AS A FREE-FLYER)
- 3- SUPPORT OF SATELLITES IN NEARBY INCLINATIONS AT NODAL COINCIDENCE
  - 0    SPACE TELESCOPE MAINTENANCE
  - 0    SPACE BASED RADAR (ITSS) MAINTENANCE
- 4- UNIVERSAL SUPPORT OF LEO SATELLITES
  - 0    PROMPT SATELLITE REPLACEMENT
  - 0    SHUTTLE CREW RESCUE VEHICLE
- 5- UNIVERSAL SUPPORT OF GEO SATELLITES
  - 0    GEO SATELLITE RESUPPLY

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## ADVANCED SPACE BASED RADAR (225 METER ANTENNA)

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The near-term, large antenna systems use deployable systems which can be contained in a single Space Shuttle launch. Experiments designed to study the dynamics of such systems are planned as part of the Space Shuttle experiment program. The limits of these systems are yet to be accurately determined, but they are presently assumed to be on the order of 100 to 150 m. Development hardware has been fabricated for deployable systems with a diameter of 110 m.

Advanced system studies have defined a need for larger antenna (225 m) for use in space-based radar operating at geosynchronous altitudes. Structures of this size cannot be constructed using unfurlable systems and present designs assume it will require on-orbit construction. The Space Shuttle can provide a platform for support of construction activities, but the limited time on orbit imposes constraints on the system that may be excessively restrictive. The space station offers an ideal platform for large space construction since it can provide all necessary support services required during fabrication and checkout. It also will supply the transfer vehicle base for launch of the system into its operating orbit.

The users for this system are not specifically defined since the concept is a product of the Air Force/AIAA technology mission model. This configuration is an outgrowth and an extension of near-term concepts such as the Integrated Tactical Surveillance System (ITSS) space-based radar (discussed later in this section).





## ADVANCED SPACE-BASED RADAR (225 METER ANTENNA)

### SYSTEM DESCRIPTION:

1. PURPOSE: TO VIEW IN A SURVEILLANCE MODE SPECIFIC EARTH GEOGRAPHICAL LOCATIONS FOR INFORMATION GATHERING, EXAMINATION AND VERIFICATION
2. LIFETIME: 5 TO 10 YEARS (INCLUDING SERVICING)
3. LAUNCH AND TRANSFER VEHICLE: SHUTTLE TO STATION, PROPULSION MODULE (LEO TO GEO XFER) AND POSSIBLE TELEOPERATOR
4. OPERATIONAL LOCATION: PRIMARY-GEO
5. TOTAL MASS AT OPERATIONAL LOCATION: APPROXIMATELY 150,000 KG
6. AVERAGE OPERATIONAL POWER: APPROXIMATELY 15,000 WATTS
7. DESIRED INITIAL OPERATIONAL DATE: 1988 (SHUTTLE BASED EXPERIMENT: 60 M REFLECTOR)  
1993 (STA CONSTRUCTED WITH SBR LAUNCH TO GEO)
8. GENERAL NEEDS:
  - CONSTRUCTION AT STATION: BOTH IVA AND EVA CREW SUPPORT PLUS CONSTRUCT EQUIP.
  - SBR PLATFORM STABILITY ~1/10 OF ANTENNA BANDWIDTH
  - DATA RATE OF ~50 M/BITS/SEC
  - PROPULSION MODULES FOR TRANSPORT FROM LEO TO HEO
  - POTENTIAL USE OF TELEOPERATOR
  - PHYSICAL CHARACTERISTICS: 225 M ANTENNA (REFLECTOR SIZE)
  - ON-ORBIT SERVICING
  - STATION C/O OF SBR PRE/POST LAUNCH TO GEO
  - COMM/DATA LINKS STA TO GROUND AND TO MILSTAR AND TDRSS.

EARTH/SPACE OBSERVATION MISSION

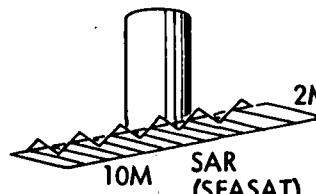
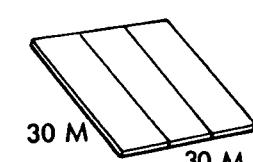
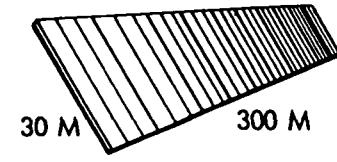
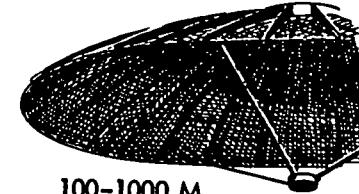
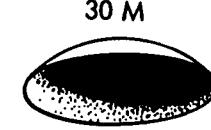
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Several configurations of arrays, antennas, and optical reflectors and their supporting systems have been proposed for operation in space. A number of such configurations are shown through a series of evolutionary steps.

These structures will require staging in a low earth orbit before being launched into their final operating orbits.



## EARTH/SPACE OBSERVATION MISSION

	PRESENT TECHNOLOGY HARDWARE	LEO MISSION HARDWARE	GEO MISSION HARDWARE	CRITICAL CONCEPT TO BE VALIDATED
RADAR	 SAR (SEASAT) PLANAR PHASED ARRAY	 PLANAR PHASED ARRAY	 PLANAR PHASED ARRAY	<ul style="list-style-type: none"> <li>• SURFACE ACCURACY</li> <li>• POSITIONING OF FEEDS</li> </ul>
RF/MICROWAVE	 15M PARABOLIC ANTENNA	 30 M PARABOLIC ANTENNA	 100-1000 M PARABOLIC ANTENNA	<ul style="list-style-type: none"> <li>• SURFACE ACCURACY</li> <li>• POSITIONING OF FEEDS</li> </ul>
OPTICAL	 1 M TELESCOPE	 30 M OPTICAL REFLECTOR PARABOLIC	 30-50 M OPTICAL REFLECTOR PARABOLIC HIGH-RESOLUTION	<ul style="list-style-type: none"> <li>• SURFACE ACCURACY</li> <li>• LONG LIFE OPTICAL PROPERTIES</li> </ul>

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ASTRONOMY PLATFORM - TETHERED

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One of the science platforms to be considered for support by a space station is an astronomy platform. The contamination surrounding the space station will require that the astronomy payload be placed some distance from the central station complex. In addition the platform must have certain pointing and stability requirements as indicated on the attached sheet. One way to provide the proper environment for the astronomy platform is to support it by a tether connected to the space station. The tether will provide communications and power as well as providing a physical support to the station. Because the tether cannot transmit compressive loads there will be minimal interference from local disturbances on board the station. There will be a low level gravity field induced as a result of having a tether, but the levels should be sufficiently small so that this will not impose an operational constraint on the astronomy platform.

The concept of tethering the payload is based on the desire to minimize system complexity that would be involved if the telescope were to be placed on a free flying platform. By use of the tether we can eliminate the need to provide communication systems, power systems, and a complete attitude control system although the tether provides only two access stabilization and some onboard attitude control is required for the third access. Tethered payloads for earth observation or material processing are comparatively straight forward since it is either desirable or immaterial that the tether causes the payload to remain in a earth looking orientation throughout the orbit. For an astronomy platform the tether will need to be connected to a rotary joint at the platform's center of mass in order to allow the payload itself to remain in initial orientation. This rotary joint considerably complicates the transmission of electric power, communications, and data and this added complexity may negate the advantages of this system compared to a free flying platform.

As in the previous case this mission scenario is generic in nature and no specific users have been identified. Programs such as the shuttle infrared telescope facility (SIRTF) could take advantage of this concept for support by the space station since an appropriately designed system would allow direct installation of shuttle compatible payload pallets.





## ASTRONOMY PLATFORM TETHERED

### SYSTEM DESCRIPTION:

#### 1. PURPOSE:

- ASTRONOMY PLATFORMS - OBSERVE PLANETARY AND CELESTIAL PHENOMENA
- ALTERNATIVES: EARTH RESOURCES EXAMINATION, SPACE EVALUATION, SOLAR OBSERVATION AND EARTH-SUN STUDIES

#### 2. LIFETIME: 5 TO 15 YEARS (INCLUDING SERVICING)

#### 3. LAUNCH AND TRANSFER VEHICLE:

- SHUTTLE - PAYLOAD TO ORBIT AT STATION
- SHUTTLE-SPARES/FLUIDS TO STATION
- P/L HANDLING UNIT - TETHER

#### 4. OPERATIONAL LOCATION: STATION AT 28.5°, 200-300 NMI

TETHER TO PLACE P/L AT LEAST 5 NMI ABOVE STATION

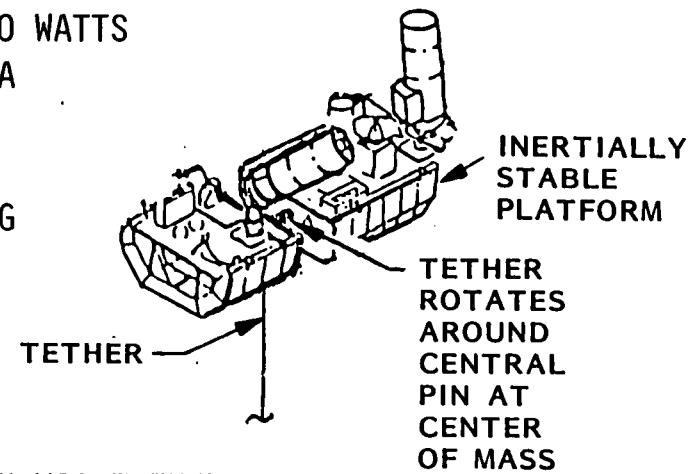
#### 5. TOTAL MASS AT OPERATIONAL LOCATION: APPROXIMATELY 15 TO 25 kLB

#### 6. AVERAGE OPERATIONAL POWER: TBD; BACKUP POWER ~500 WATTS

#### 7. DESIRED INITIAL OPERATING DATE: EARLY STATION ERA

#### 8. GENERAL NEEDS:

- ON-ORBIT SERVICES
- CAPTURE AND HOLDING/POSITIONING FOR SERVICING
- SPARES AND FLUIDS RESUPPLY
- POTENTIAL USE OF P/L HANDLING UNIT
- CHECKOUT DATA RATE OF 15 TO 25 KBS
- PHYSICAL CHARACTERISTICS: 8 TO 14.5' DIAM,  
10 TO 45' LONG
- COMM/DATA LINKS: HIGH DATA RATE TRANSMISSION VIA TETHER





## SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

THESE MISSION SCENARIOS HAVE BEEN SELECTED TO COVER THE FIVE CATEGORIES OF SPACE OPERATIONS

### ON-BOARD OPERATIONS

- 1- HARD DOCKED PAYLOADS, CAPTIVE FREE-FLYER, AND TETHERED SATELLITES
  - o LARGE STRUCTURES ASSEMBLY (LARGE ANTENNA FOR SPACE RADAR)
  - o ASTRONOMY PLATFORM SUPPORT (TETHERED)

### REMOTE OPERATIONS

- 2- SUPPORT OF SATELLITES IN LOCAL STATION VICINITY
  - o ASTRONOMY PLATFORM SUPPORT (AS A FREE-FLYER)

- 3- SUPPORT OF SATELLITES IN NEARBY INCLINATIONS AT NODAL COINCIDENCE
  - o SPACE TELESCOPE MAINTENANCE
  - o SPACE BASED RADAR (ITSS) MAINTENANCE

- 4- UNIVERSAL SUPPORT OF LEO SATELLITES
  - o PROMPT SATELLITE REPLACEMENT
  - o SHUTTLE CREW RESCUE VEHICLE

- 5- UNIVERSAL SUPPORT OF GEO SATELLITES
  - o GEO SATELLITE RESUPPLY

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ASTRONOMY PLATFORM - FREE FLYER

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This mission description is identical in almost all respects to that for Astronomy Platform - Tethered. Obviously, the free-flying platform can be used for Earth resources experiments and operational activities as well as for astronomical purposes. The specific instrumentation and payload configurations will be different in the two cases. The primary change in this payload system from the tethered configuration is that free-flying platforms now require onboard attitude control, drag makeup, propulsion capability, communications, power, and docking/berthing/capture features. This payload platform is considerably more sophisticated than the tether system.

The use of free flyers as opposed to tethered systems for payload support will affect space station architecture. For a tethered system, payloads can be reached by "simply" reeling in the tether. No additional orbit transfer system is required. For a free-flying system, a small orbit transfer vehicle (OTV) such as a TMS will be required. In addition, a space to berth the payload will be required, perhaps a different area than the service area for Shuttle-based payloads.

This payload mission scenario is generic in the sense that many different types of user can take advantage of space-based servicing and would want payloads to remain in close proximity to the space station (e.g., development platforms for sensors, material processing research facilities, and astronomical observatories such as SIRTF). The user community for this class of payloads is not well defined since users have not defined their requirements beyond statements of general interest. The division between hard-docked and free-flying payloads has not been made in most cases.





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## ASTRONOMY PLATFORM FREE FLYER

### SYSTEM DESCRIPTION:

#### 1. PURPOSE:

- ASTRONOMY PLATFORMS - OBSERVE PLANETARY AND CELESTIAL PHENOMENA
- MMS DERIVITIVES - EARTH RESOURCES EXAMINATION, SPACE EVALUATION, SOLAR OBSERVATION AND EARTH-SUN STUDIES

#### 2. LIFETIME: 5 TO 15 YEARS (INCLUDING SERVICING)

#### 3. LAUNCH AND TRANSFER VEHICLE:

- SHUTTLE - S/C TO ORBIT
- SHUTTLE-SPARES/FLUIDS TO STATION
- SHUTTLE - SPARES/FLUIDS FOR SERVICING (PRE-STA ERA)
- P/L HANDLING UNIT (TMS XFER TO/FROM STA)

#### 4. OPERATIONAL LOCATION: LEO AT 28.5° AND 10 NMI FROM STATION ALT WITHIN $\pm 35^\circ$ (IN PLANE) FROM STATION

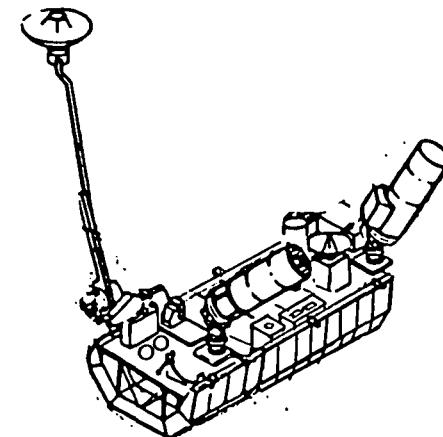
#### 5. TOTAL MASS AT OPERATIONAL LOCATION: APPROX 15 TO 25 KLB

#### 6. AVERAGE OPERATIONAL POWER: TBD

#### 7. DESIRED INITIAL OPERATING DATE: VARIES FROM 1984 TO 1988 +

#### 8. GENERAL NEEDS:

- ON-ORBIT SERVICING
- CAPTURE AND HOLDING/POSITIONING FOR SERVICING
- SPARES AND FLUIDS RESUPPLY
- POTENTIAL USE OF P/L HANDLING UNIT
- CHECKOUT DATA RATE OF 15 TO 25 KBS
- PHYSICAL CHARACTERISTICS: 8 TO 14.5' DIAM, 10 TO 45' LONG, & ARRAYS UP TO 20' EA
- COMM/DATA LINES: S/C TO TDRSS (UP AND DOWN LINK), POSSIBLE STATION LINK





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## SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

THESE MISSION SCENARIOS HAVE BEEN SELECTED TO COVER THE FIVE CATEGORIES OF SPACE OPERATIONS

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  - o ASTRONOMY PLATFORM SUPPORT (TETHERED)

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  - o ASTRONOMY PLATFORM SUPPORT (AS A FREE-FLYER)
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  - o SPACE TELESCOPE MAINTENANCE
  - o SPACE BASED RADAR (ITSS) MAINTENANCE
- 4- UNIVERSAL SUPPORT OF LEO SATELLITES
  - o PROMPT SATELLITE REPLACEMENT
  - o SHUTTLE CREW RESCUE VEHICLE
- 5- UNIVERSAL SUPPORT OF GEO SATELLITES
  - o GEO SATELLITE RESUPPLY

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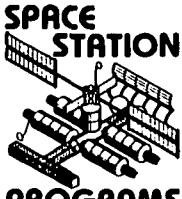
 Lockheed

ESTABLISHING THE NEED FOR ON ORBIT SERVICING

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As we enter the Shuttle era, more consideration is being given to the design of satellites for servicing. Although only a few satellites currently in orbit have been designed for servicing (e.g., Solar Max), many spacecraft currently in detailed design or hardware fabrication stages (such as Space Telescope) are designed for on-orbit servicing and maintenance. As users begin to exploit the capabilities of the Shuttle and space station for servicing, more satellites will incorporate necessary hardware designs to allow on-orbit maintenance, repair, and equipment update. Some key considerations in defining the level of servicing to be accommodated are indicated on the opposite page.

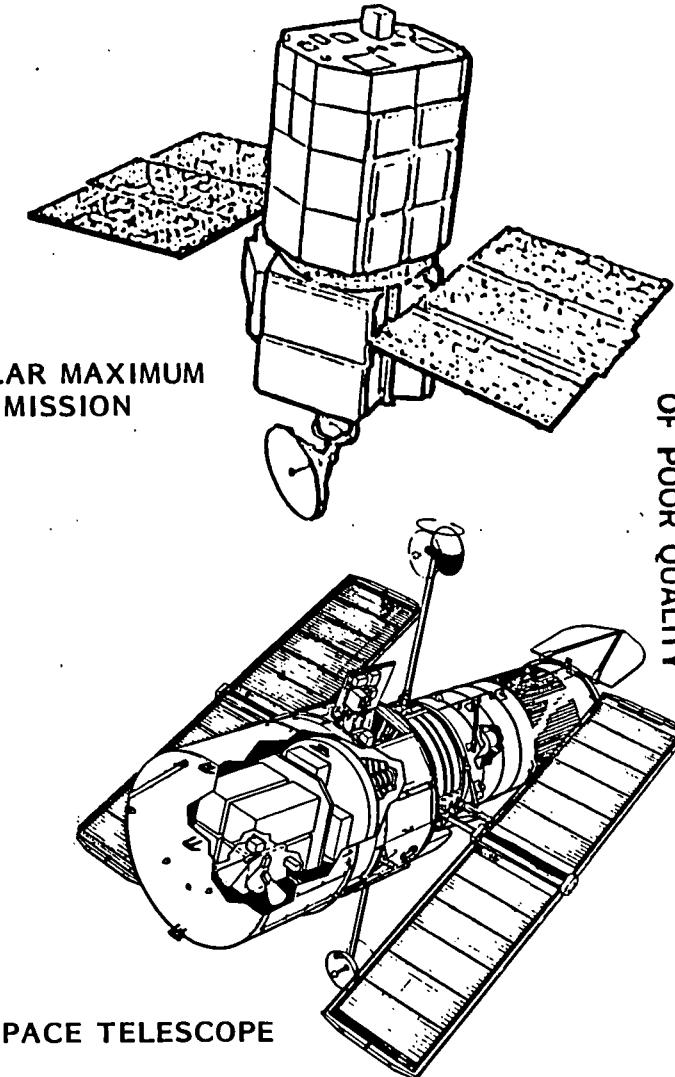




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## ESTABLISHING THE NEED FOR ON-ORBIT SERVICING

1. RELIABILITY AND MTBF FACTORS
2. ITEMS HIGHLY SUSPECT TO MALFUNCTION BUT WITH LIMITED FLIGHT RELIABILITY DATA
3. PREVENTIVE MAINTENANCE CONSIDERATIONS
4. WEAR-OUT LIFETIMES
5. DEGRADATION LIFETIMES
6. ITEMS THAT MAY RECEIVE INADVERTENT COLLATERAL DAMAGE
7. ITEMS SUBJECT TO EMI OR OTHER 'SIGNAL' SPECTRA DAMAGE
8. INDUCED DAMAGE, E.G., LOSS OF THERMAL CONTROL AND SUBSEQUENT CHANGE OF TEMPERATURE PAST SURVIVABILITY LEVEL
9. MICRO-METEORITE PENETRATION/DAMAGE
10. CASCADING FAILURES OR POWER SURGES
11. EQUIPMENT/EXPERIMENT ITEM UPDATE/REPLACEMENT
12. NEW PAYLOAD REPLACEMENT
13. COMPLETE SUBSYSTEM REPLACEMENT
14. ETC.



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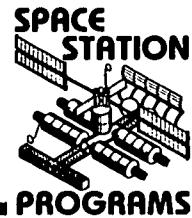
PLANNED MISSION DISTRIBUTION

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A mission model has been developed to determine the number of satellites to be in orbit from 1982 through 1992. Satellites were categorized by operational inclination and altitude and the number of satellites in each category is displayed on the facing page. Many users place satellites in specific orbits for specific requirements; however, most civilian satellites are contained in two orbits (28.5 and 98 deg). As discussed earlier, scheduled maintenance and repair for satellites is done most efficiently at nodal coincidence; energy limitations require that a space station be at 28.5 deg and 90. to 98 deg if most civilian satellites are to be serviced from a space-based system.

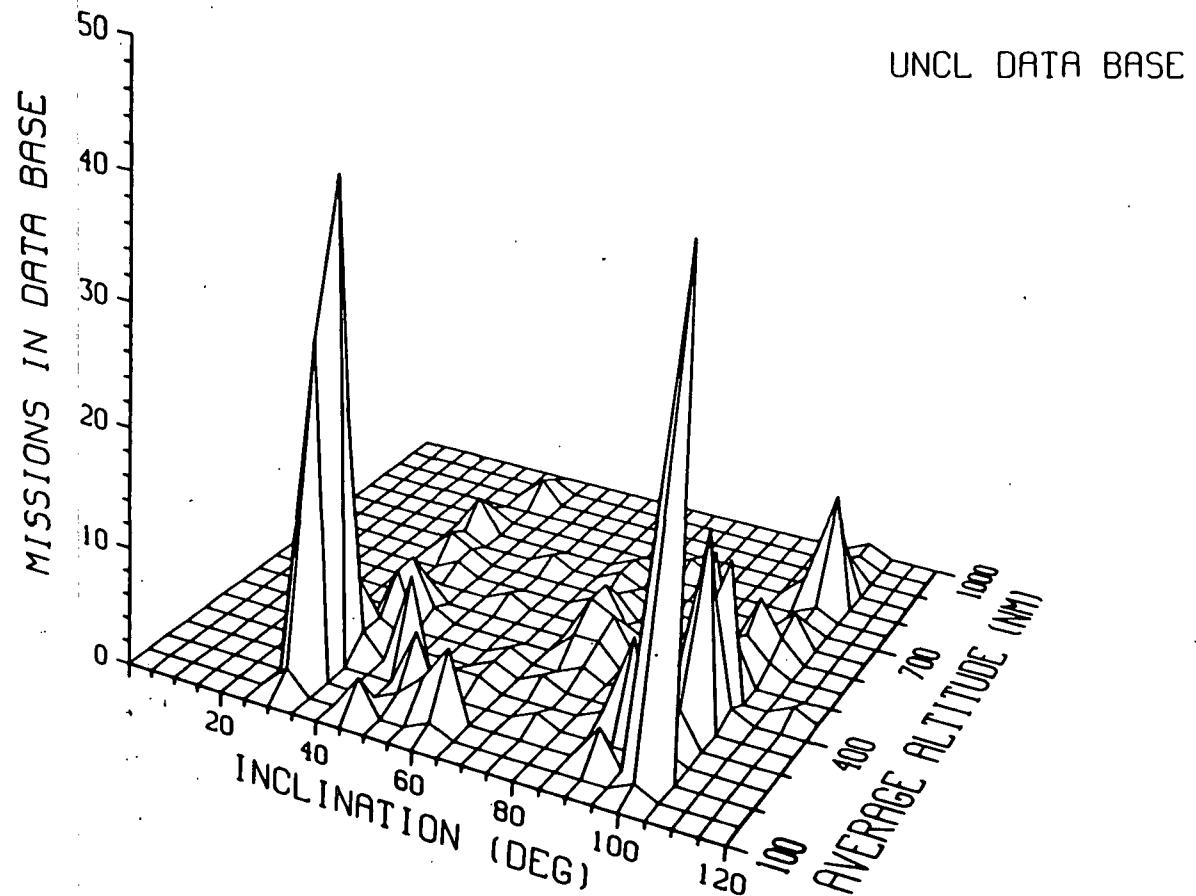
This mission model containing 655 satellites is speculative because not all missions are approved or under way. The fact that most of satellites cluster in two inclinations indicates that many satellites can be serviced from a space-based system and that it makes sense to consider servicing as a primary function of a space station. An economic trade study comparing Space-Shuttle-based servicing with space-station-based servicing shows a substantial cost advantage to the space station system even if only a few satellites are serviced in a given year.





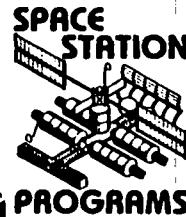
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## PLANNED MISSIONS DISTRIBUTION



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**SPACE TELESCOPE  
FIRST SPACE FACILITY  
DESIGNED FOR  
ON-ORBIT MAINTENANCE**

 Lockheed

The Lockheed logo consists of a stylized five-pointed star or arrowhead pointing upwards and to the right, positioned to the left of the company name.

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SPACE TELESCOPE SYSTEM

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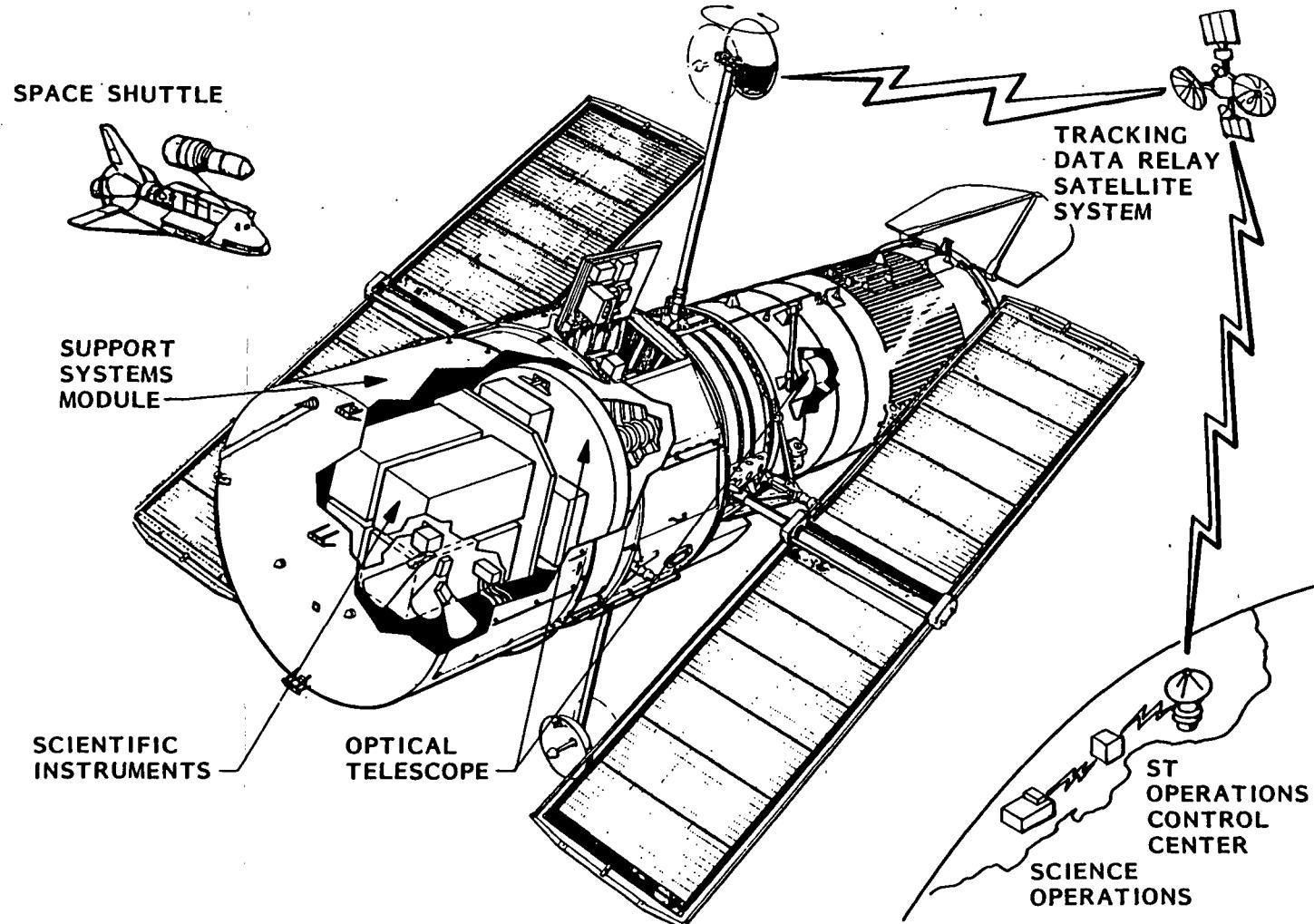
The Space Telescope is in production, with the first flight scheduled for 1985. This system was designed from the outset for space-based servicing and will be one of the first space facilities built with that as an underlying design philosophy. The space telescope is in a 28.5deg, 300-nmi orbit. The plans are for a scheduled maintenance at 2-1/2 years after launch. The interval between nodal coincidences between a space station at 28.5 deg and 220-nmi and a satellite at 28.5 deg and 300-nmi is approximately 23 months. This is consistent with the scheduled Space Telescope maintenance interval and thus the station is a suitable base for this type of operation.





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## SPACE TELESCOPE SYSTEM



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SPACE TELESCOPE FEATURES

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The Space Telescope is designed for three levels of maintenance and refurbishment as shown in the chart on the facing page. We are concerned here only with orbital maintenance, even though the space station can play a secondary role in the preparation for retrieval of the Space Telescope for transport to the ground and for minimum checkout on relaunch. It is also possible that the presence of a station may change the design philosophy on the trade between on-orbit repairs and repairs made on the ground. It may be more economical to perform more maintenance at the space station.





## SPACE TELESCOPE FEATURES

SPACE TELESCOPE IS DESIGNED FOR THREE LEVELS OF MAINTENANCE AND REFURBISHMENT:

### ORBITAL MAINTENANCE

- CRITICAL COMPONENTS REPLACEABLE IN ORBIT
- EVA MANUAL OVERRIDE OF MECHANISMS IF REQUIRED AT DEPLOYMENT/RETRIEVAL/MAINTENANCE
- SCIENCE INSTRUMENTS REPLACEABLE IN ORBIT
- OTHER COMPONENTS REPLACEABLE IN ORBIT ON A CONTINGENCY BASIS; FULL EXTENT OF CAPABILITIES TO BE DETERMINED BY GROUND TEST AND CONTINUOUS ON-ORBIT ANALYSIS

### GROUND MAINTENANCE

- MOST COMPONENTS REPLACEABLE AS REQUIRED AT KSC

### GROUND REFURBISHMENT

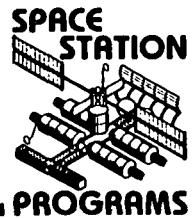
- DISASSEMBLE, REPLACE/REPAIR, REASSEMBLE, AND VERIFY

## ORBIT REPLACEABLE UNITS (ORUs) IN THE SPACE TELESCOPE

There are three basic categories of ORUs in the Space Telescope. Twenty-three ORUs are presently incorporated into the design and the basic engineering has been completed to increase this quantity if desired. Among other reasons, it was found to be more economical to replace trays of components than to replace individual components. It may be that repair and modification of ORUs can be performed on orbit for certain components, but refurbishment for the most part will probably be performed on the ground.

Although some ORUs are quite large, they can be handled by a suited astronaut as demonstrated in the neutral buoyancy tank at NASA-MSFC. The current plan is to place the Space Shuttle in orbit near the Space Telescope to perform the necessary maintenance. In the space station support mode, astronauts could maneuver to the Space Telescope using a manned maneuvering unit supported by a TMS loaded with appropriate ORUs for changeout at operational altitude. An alternate is to move the Space Telescope to the space station for maintenance. A delta velocity of less than 600 ft/sec is required for the roundtrip maneuver.

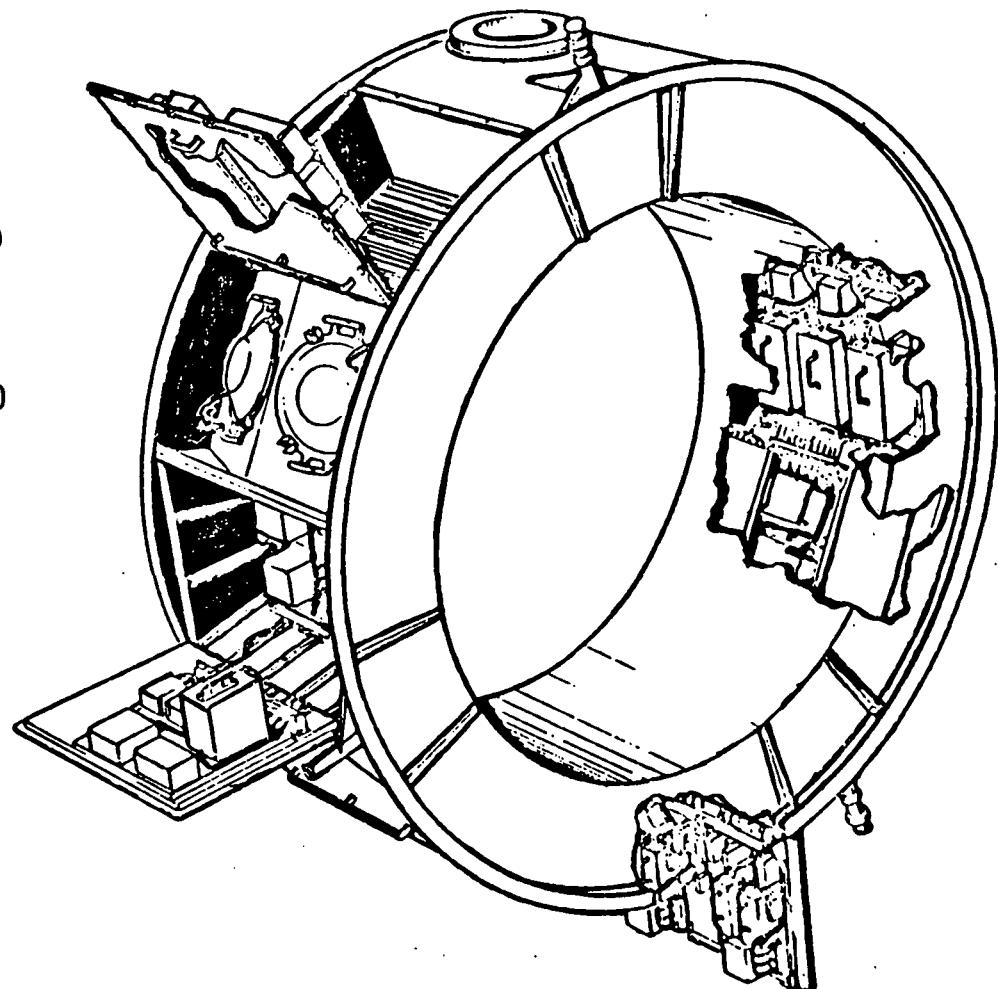




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## ORBITABLE REPLACEABLE UNITS (ORUs) IN THE SPACE TELESCOPE

- LARGE MODULES:
  - SCIENCE INSTRUMENTS (5)
  - FINE GUIDANCE SENSOR (FGS) (3)
- SMALL MODULES
  - SCIENCE INSTRUMENT CONTROL AND DATA HANDLING (SI C&DH) (1)
  - RATE SENSOR UNIT (RSU) (3)
- COMPONENTS
  - ELECTRONICS FOR RSU (3)
  - ELECTRONICS FOR FGS (3)
  - BATTERIES (5)
- TOTAL: 23



Lockheed Missiles & Space Co.

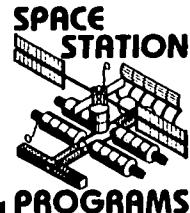
 Lockheed

SPACE TELESCOPE FEATURES - SMALL MODULE ORU

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A typical science instrument control and data handling ORU is shown on the facing page. One function of the ORU is to allow changeout of groups of components for (perhaps ground-based) repair and maintenance. Another, perhaps primary, function is to allow reconfiguration of science and experimental payloads.



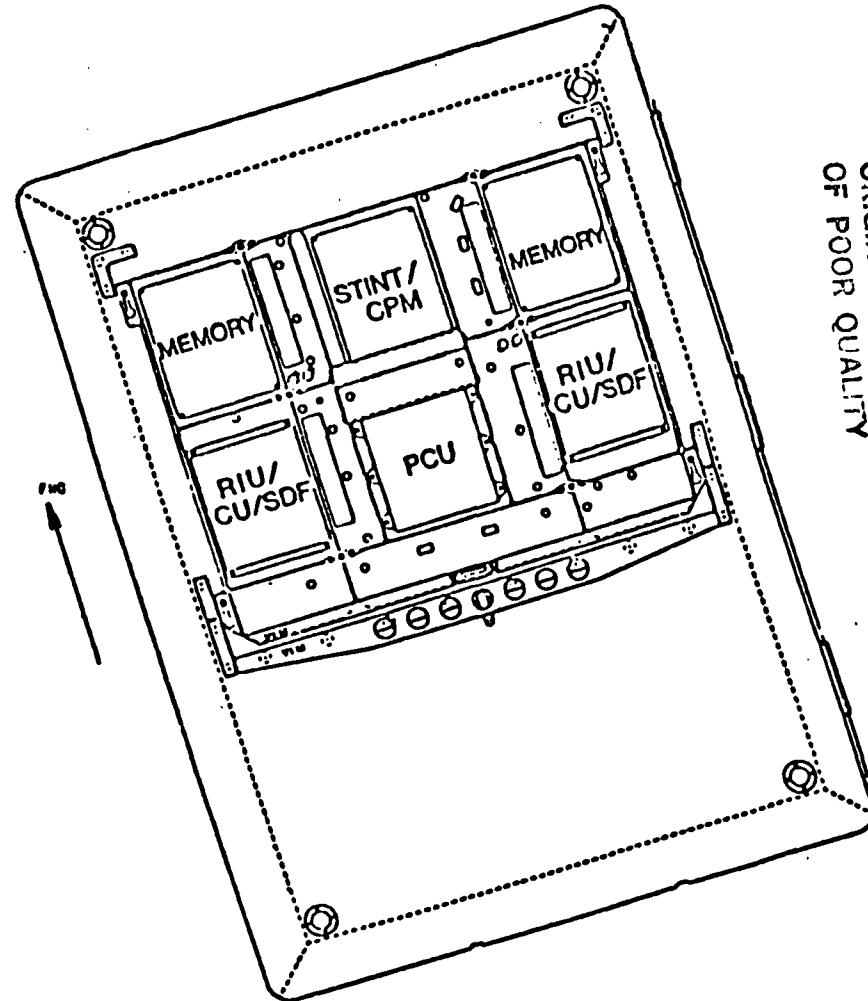


SCIENCE INSTRUMENT  
CONTROL AND DATA  
HANDLING (SI C&DH)

## ST FEATURES - SMALL MODULE ORU (EXAMPLE)

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INSTALLATION CONCEPT FOR ORU

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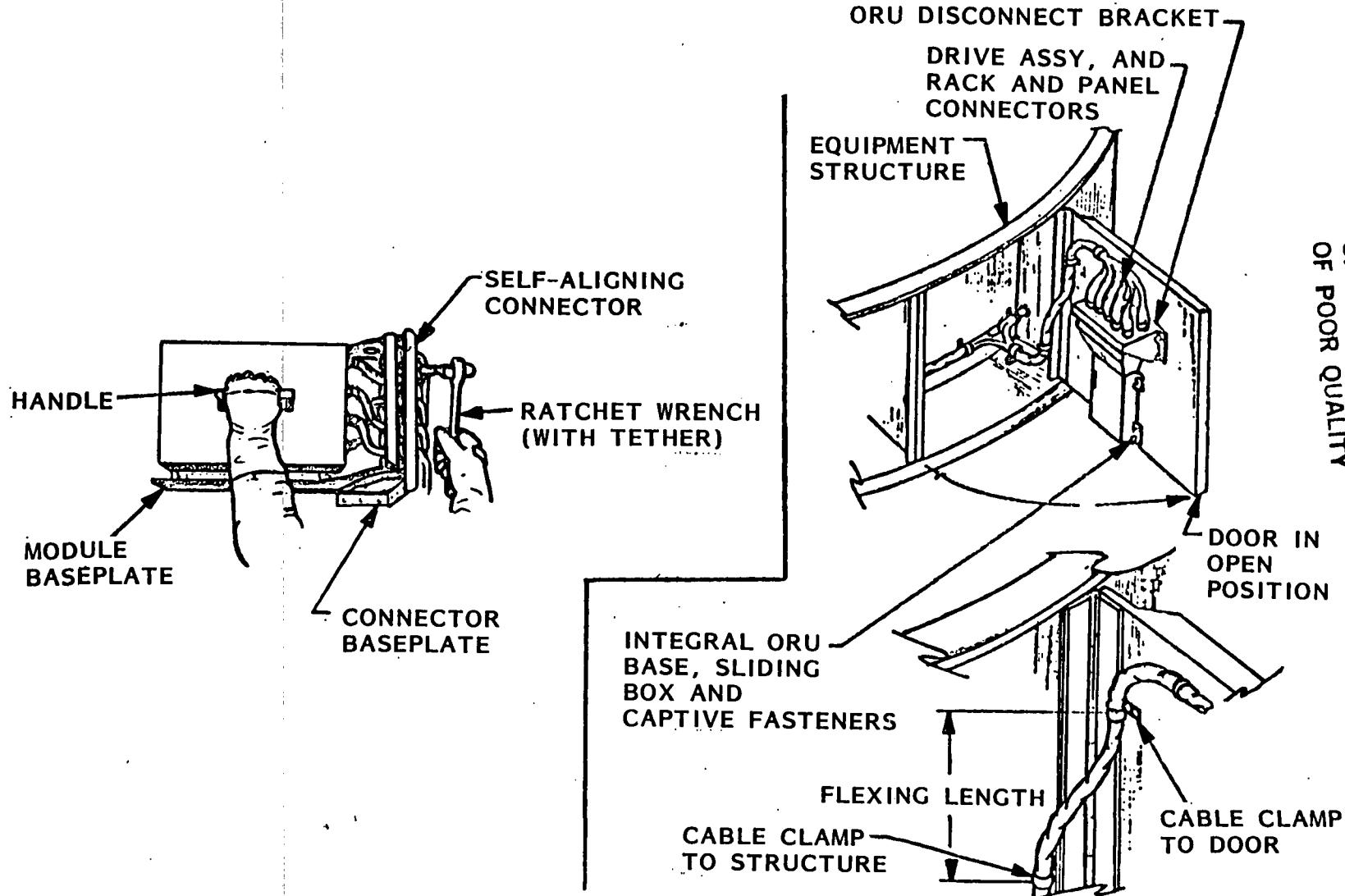
In the Space Telescope design, a number of hardware components with special features were developed as illustrated on the facing page. These features can be standardized and will make the design of spacecraft for maintenance, repair, and servicing on orbit much simpler to implement on future systems.





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## INSTALLATION CONCEPT FOR ORBITAL REPLACEMENT UNIT (ORU)



ORU DESIGN PRINCIPLES

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Several key issues in the development of ORU designs are listed on the facing page. The development of standardized on-orbit servicing techniques and auxiliary support equipment will reduce the cost for implementation of on-orbit design features for most payloads. The fundamental approach to design for on-orbit servicing must be established early in the preliminary design phase for a payload or spacecraft. These features, when incorporated in new satellite configurations, will allow the user to fully realize the benefits of both the Space Shuttle and the space station in taking advantage of man's presence on orbit as a means of reducing total program costs.





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## ORU DESIGN PRINCIPLES

- DEVELOPMENT OF STANDARDIZED ON-ORBIT EVA OR IVA, SERVICE TECHNIQUES AND AUXILIARY SUPPORT EQUIPMENT FOR MOST SHUTTLE PAYLOADS OR SPACE STATION MODULES WILL REDUCE COST.
- EARLY DEFINITION OF UNIQUE CREW SYSTEM REQUIREMENTS TO CONTRACTOR AND SUBCONTRACTORS WILL REDUCE COST.
- A NEUTRAL BUOYANCY PROGRAM IN COMBINATION WITH GROUND TEST AND ANALYSIS SHOULD PRECEDE FINAL DESIGN.
- EARLY DEFINITION OF SHUTTLE AND SPACE STATION INTERFACES WILL MINIMIZE DESIGN CHANGES.
- ALL DEPLOYABLES SHOULD BE DESIGNED FOR MANUAL (EVA) DEPLOYMENT, RETRACTION, AND JETTISON WHILE ATTACHED TO SHUTTLE/ORBITER OR SPACE STATION.



## ORU DESIGN PRINCIPLES (CONT)

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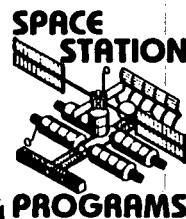
Additional considerations in the design of ORUs are shown on the facing page. Care must be exercised in selecting components to be designed for replacement on orbit. Cost trade studies on reliability versus maintenance costs are a key in this decision process. The size and complexity of each ORU must be traded against the number of spares and amount of special test equipment required. Simple ORU configurations with only a few components will reduce the individual ORU cost but will increase the number of different ORU's required in inventory on-orbit. Larger ORUs with more components are more expensive, but simplify the inventory problem. The proper choice will be based on the specific spacecraft design.





## ORU DESIGN PRINCIPLES (CONT)

- EARLY DETERMINATION OF TYPE OF ORU REQUIREMENTS SHOULD BE MADE BASED ON COMPONENT RELIABILITY, REDUNDANCY, AND MISSION CRITICALITY.
  - COST TRADE STUDIES ON RELIABILITY VERSUS MAINTENANCE COSTS SHOULD BE CONDUCTED BEFORE DECIDING ON ORUS.
  - DEGREE OF ORU CAPABILITY FOR EACH ITEM SHOULD BE SELECTIVELY ASSIGNED RATHER THAN GENERALIZED.
  - DEGREE OF MODULARITY SHOULD BE SELECTED BASED IN PART ON REDUCING NUMBER OF SPARES AND GROUND TEST REQUIREMENTS.
- VEHICLE CONFIGURATION SHOULD BE OPTIMIZED FOR:
  - ACCESS
  - EQUIPMENT ARRANGEMENTS
  - UNIQUE REQUIREMENTS



# **U.S. NATIONAL SECURITY SPACE OPERATIONS MISSION SCENARIO**

**LOW EARTH ORBIT (LEO)  
SPACE-BASED RADAR (SBR)  
FOR INTEGRATED TACTICAL  
SURVEILLANCE SYSTEM (ITSS)**

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## INTEGRATED TACTICAL SURVEILLANCE SYSTEM (ITSS) SPACE BASED RADAR

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A study was recently performed to evaluate a space based radar satellite constellation as part of the integrated tactical surveillance system for the Navy. The study included an evaluation of on-orbit servicing as a key part of its design.

The individual satellites are launched from the Shuttle and carry onboard propulsion to transfer from the Shuttle orbit to the operational altitude. In analysis of this system for space based servicing, the requirement was that the satellite would return to the Shuttle operational altitude under its own power with onboard propellant. This requirement forced an increase in the size of the onboard propellant system and resulted in a substantial reduction in payload capability. For that reason on-orbit servicing was rejected as an option in that study.

An alternative to carrying onboard propellant to return the satellite to the Space Shuttle would be to use an OTV (carried to orbit by the Shuttle) to retrieve the satellite and return it to the Shuttle for servicing. This approach was rejected in the ITSS study because the OTV capability for automated docking and retrieval operations does not currently exist, and an operational system will not be available by the end of this decade. The ITSS program did not include an OTV development effort and this option was not explored further. For our present purposes, however, this is a viable option to consider for the 1990s, and it will be compared with space station based OTV servicing of satellites.

This specific scenario was chosen because it was representative of the next generation of satellites currently being designed for operation in the late 1980s. This specific configuration is representative of a broader class of generic systems which have similar requirements. The satellite mass and size is considered representative of those to be used in the shuttle era.



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## INTEGRATED TACTICAL SURVEILLANCE SYSTEM SPACE-BASED RADAR

### OBJECTIVE:

- TO INFORM U.S. NAVY AND AIR FORCES CONCERNING PENDING AERIAL ATTACKS
- TO DEFINE THE NAVY SURVEILLANCE/COMMAND, COMMUNICATION AND CONTROL IMPROVEMENTS IN SUPPORT OF ANTI-AIR WARFARE AND SURFACE/SUBSURFACE WARFARE

### SYSTEM DESCRIPTION:

- MULTIPLE SATELLITES ( 3 )
- LIFETIME > 3 YR
- LAUNCH & TRANSFER VEHICLE: INITIAL LAUNCH FROM SHUTTLE
- OPERATIONAL LOCATION: 600 & 1400 NMI AT BOTH 57 DEGREES & 65 DEGREES
- TOTAL MASS AT OPERATIONAL LOCATION: 23,000 TO 25,000 LB
- AVERAGE OPERATIONAL POWER: 13 kW AVERAGE
- DESIRED INITIAL OPERATIONAL DATE: EARLY 1990

**INTEGRATED TACTICAL SURVEILLANCE SYSTEM (ITSS)  
SPACE-BASED RADAR (CONT)**

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General requirements for servicing the space-based radar (SBR) are shown on the facing page. Primary resupply items are for propellant and 8 major equipment items.

This SBR system is compatible with the Shuttle, is contained in a single launch, and has unfurlable or deployable appendages. It is much smaller than the large space structure antenna for a 225 m SBR to be operated in geostationary satellite orbits.





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## **INTEGRATED TACTICAL SURVEILLANCE SYSTEM (ITSS) SPACE-BASED RADAR**

### GENERAL NEEDS:

- SERVICING FROM STATION: FUEL/OX/PRESSURANT RESUPPLY EQUIPMENT CHANGEOUT - VARIOUS ITEMS IN 8 SUBSYSTEMS
- STATION SUPPORTS SERVICING & ITSS CHECKOUT AFTER SERVICING SCENARIO
- SERVICING USES STATION-BASED TELEOPERATOR OR "MINI OTV/MOTV"
- DATA LINK TO STATION FOR SERVICING CHECKOUT 10 MBITS/SEC



ITSS SPACE BASED-RADAR SERVICING ALTERNATIVES

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Several alternatives for servicing were considered: Space-Shuttle-based servicing, space-station-based servicing, and eliminate servicing from design considerations. An option in studying these alternatives is to use onboard propulsion versus an OTV for transfer from the operational altitude down to the Space Shuttle or space station altitude. Based on ITSS study results, the integral propulsion system was dropped from consideration because of the excessive penalty imposed on the satellite payload. Three cases involving OTV support for servicing operations are discussed in the following pages.





# ITSS SPACE-BASED RADAR SERVICING ALTERNATIVES

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## ALTERNATIVES CONSIDERED:

- SHUTTLE BASED SERVICING
  - SATELLITE INTEGRAL PROPULSION
  - OTV
- SPACE STATION BASED SERVICING
  - SATELLITE INTEGRAL PROPULSION
  - OTV
- NO SERVICING
  - LAUNCH ANOTHER SATELLITE WHEN ORIGINAL HAS FAILED OR HAS DEPLETED EXPENDABLES

## ALTERNATIVES DESCRIBED IN THIS REPORT

CASE A

CASE B

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ITSS SPACE-BASED RADAR (SBR)  
CASE A - SHUTTLE-BASED SERVICING

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In this scenario the satellite is serviced by an OTV which is taken to orbit by the Space Shuttle. The OTV is used to retrieve the satellite from orbit and return it to shuttle altitude for basic repair or maintenance. An alternative studied but not included here is to perform on-orbit repair and maintenance with an automated OTV. The level of sophistication to perform such remote operations are considered second generation and warrant further study once the fundamental issues discussed here have been evaluated carefully.

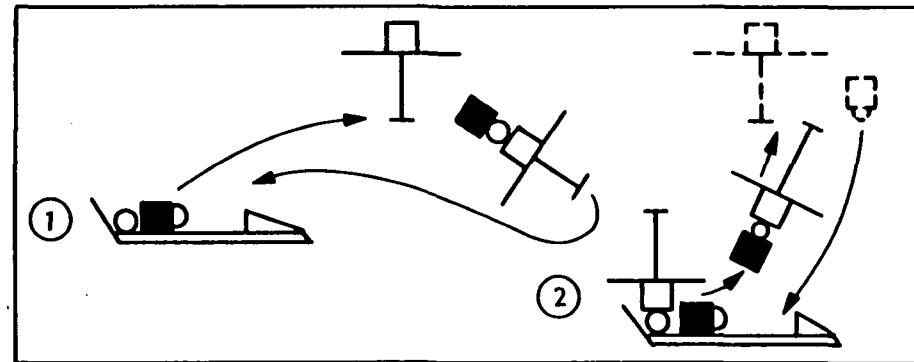




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## ITSS SPACE-BASED RADAR (SBR) CASE A - SERVICING FROM SHUTTLE

- A. SBR SERVICING LIMITED TO FUEL REPLENISHMENT
- B. OTV USED AS SERVICING VEHICLE
- C. SHUTTLE AT 2 ALTERNATIVE ALTITUDES AND INCLINATIONS FOR OTV SERVICING:
  1. OPTIMUM POINT FOR OTV NODAL INTERSECT
  2. NON-OPTIMUM POINT FOR OTV NODAL INTERSECT
- D. OTV (WITH BASIC AND REPLENISHMENT FUEL) SIZED FOR ONE SHUTTLE CARGO BAY LOAD
- E. SBR FUEL REPLENISHMENT MISSION (ON-ORBIT) WILL NOT EXCEED 7 DAYS
- F. FUEL REPLENISHMENT (SBR/OTV) CONTROL OPS CONDUCTED 'REMOTELY' - SHUTTLE AND/OR GROUND



\*SHUTTLE ORBITER AT 60° AND 220 NMI

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ITSS SPACE-BASED RADAR (SBR)  
CASE B - SERVICING AT AN OPERATIONAL ALTITUDE FROM STATION

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This servicing scenario is similar to case A, except the OTV is based at the space station. As discussed in case A, repair and equipment changeout at operational altitudes are considered a second-generation evolution of an OTV and will not be considered further in this scenario. However, automated refueling is considered feasible and that is the basis for the configuration in case B.

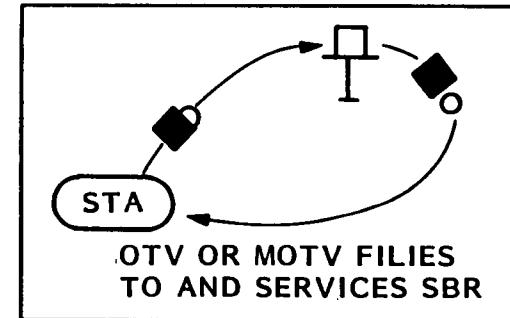




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## ITSS SPACE-BASED RADAR (SBR) CASE B - SERVICING AT OPERATIONAL ALTITUDE FROM STATION (60 DEG CIRCULAR, 220 NMI)

- A. SBR SERVICING LIMITED TO FUEL REPLENISHMENT
- B. OTV USED AS SERVICING VEHICLE
- C. STATION AT 2 ALTERNATIVE ALTITUDES AND INCLINATIONS FOR OTV SERVICING
  - 1. OPTIMUM POINT FOR OTV NODAL INTERSECT
  - 2. NON-OPTIMUM POINT FOR OTV NODAL INTERSECT
- D. OTV NOMINALLY LOCATED AT STATION STAGING AREA
- E. FUEL TANKAGE (FOR NON-STATION SUPPORT) EXISTS AT STATION
- F. FUEL FOR OTV AND SPACECRAFT (E.G., SBR) EXISTS AT STATION
  - 1. SUPPLY FUEL FOR STATION SUPPORT TANKAGE (SEE ITEM E) IS GENERIC SHUTTLE MISSION
  - 2. SBR SERVICING ASSUMES 1/4 SHUTTLE GENERAIC FUEL SUPPLY 'MANIFESTED' FLIGHT LOAD
- G. OTV FLIES TO, SERVICES (FUEL REPLENISHMENT), AND RETURNS TO STATION
- H. SBR FUEL REPLENISHMENT VIA OTV MISSION TIME DURATION NOT TO EXCEED 2 DAYS
- I. STATION PROVISIONS (HARDWARE/FIRMWARE/SOFTWARE) EXIST FOR OTV MAINTENANCE AND OPERATIONS (AT STATION AND REMOTE)



ITSS SPACE-BASED RADAR (SBR)  
CASE C - SERVICING AT STATION

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Maintenance and repair of equipment on the satellite will be performed at the space station. Since this type of support must be performed at nodal coincidence (as discussed earlier under space operations), and since the window for minimum energy transfers at nodal coincidence is comparatively short (several days), careful consideration must be given to the length of time devoted to the maintenance and repair operations. In addition to returning the satellite to a specific altitude and inclination, many spacecraft must be placed in a specific phasing within a specific plane in the operational inclination. Thus the short window at nodal coincidence is in general of importance for both retrieval and return of satellites.

The scenario described here involves placement of a spare satellite on orbit, which is then activated to replace the operational satellite being taken out of service. This avoids the time constraint imposed by orbit mechanics on servicing of the satellite. This sequence involves a series of automatic mating and demating operations on the part of the OTV. This capability exists now for near orbiter support, and it is an essential part of the TMS system which will be implemented by the late 1980s.

In cases A, B, and C, both the Shuttle and the space station are assumed to be in a 60-deg circular orbit at 220 nmi. As discussed under the section on constraints imposed by orbit mechanics, other inclinations could be used but the energy required to reach the satellite will increase substantially.

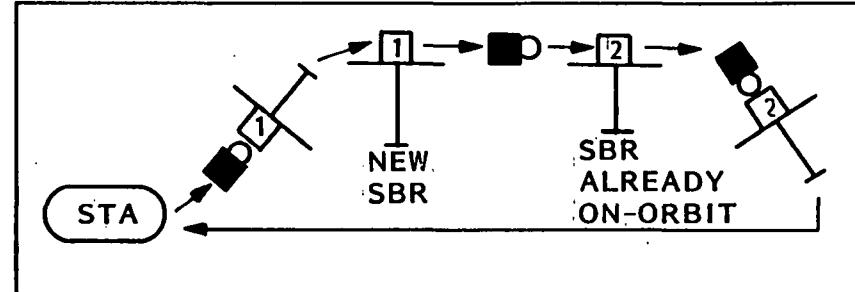




## ITSS SPACE-BASED RADAR (SBR) CASE C - SERVICING AT STATION (60 DEG CIRCULAR, 220 NMI)

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- A. SBR IS PLACED ON ORBIT
- B. OTV USED AS "LAUNCH/PLACEMENT/RECOVERY/RETURN" SPACECRAFT
- C. STATION AT 2 ALTERNATE ALTITUDES AND INCLINATIONS FOR OTV SERVICING
  1. OPTIMUM POINT FOR OTV NODAL INTERSEC
  2. NON-OPTIMUM POINT FOR OTV NODAL INTERSECT
- D. OTV NOMINALLY LOCATED AT STATION STAGING AREA
- E. FUEL TANKAGE (FOR NON-STATION SUPPORT) EXISTS AT STATION
- F. FUEL FOR OTV AND SPACECRAFT (E.G., SBR) EXISTS AT STATION
- G. OTV LAUNCHES 'SPARE' SBR FROM STATION TO SBR (TO BE SERVICED) ALT/INCL, RELEASES 'SPARE' SBR, FLIES TO AND CAPTURES SBR TO BE SERVICED, AND RETURNS SAME TO STATION
- H. SBR FULL SERVICING AT STATION IS MISSION TIME DURATION CONSTRAINED TO 'TBD' DAYS
- I. STATION PROVISIONS EXIST FOR FULL SBR SERVICING OPERATIONS
  1. STATION SERVICING CAPABILITY (HARDWARE, FIRMWARE AND SOFTWARE) IS AVAILABLE
  2. SBR SPARES (AT STATION) ASSUME 1/8 SHUTTLE 'MANIFESTED' FLIGHT LOAD
  3. FUEL FOR OTV AND SBR ASSUMES 1/4 SHUTTLE GENERIC FUEL SUPPLY 'MANIFESTED' FLIGHT LOAD



CASE STUDY OF LOGISTICS ADVANTAGES

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A cost trade study was performed to evaluate the benefit of station-based servicing versus Shuttle-based servicing for the ITSS space-based radar. In other studies of this type, it was assumed that propellant could be scavenged from the external tank and orbiter, thereby reducing the cost for on-orbit operations. While scavenged propellants may have a significant beneficial effect and certainly should be considered in the overall system design for the space station, it was assumed in this study that all propellant had to be transported to orbit by the Shuttle. This is a more conservative assumption and, if the space-station-based system proved more economical, scavenging propellants would only improve an already favorable economic trade.





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## CASE STUDY OF LOGISTICS ADVANTAGES

### CASE SELECTED FOR STUDY:

- ITSS PROGRAM
- CONSTELLATION OF 24,000 LB SATELLITES
- 1400 NMI ALTITUDE

### GROUND RULES:

- NO ET PROPELLANT SCAVENGING FOR SPACE-BASED OTV
- SCHEDULED ITSS SERVICING
- SPACE-BASED OTV FLIES ONLY AT NODAL COINCIDENCE

### CASES EVALUATED:

- A ● ITSS SATELLITES SERVICED AT 1400 NMI BY GROUND BASED OTV
- B ● ITSS SATELLITES SERVICED AT 1400 NMI BY SPACE BASED OTV
- C ● ITSS SATELLITES CARRIED TO/FROM STATION BY SPACE BASED OTV

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GROUND-BASED VERSUS STATION-BASED OTV SERVICING

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The cost comparison for servicing a space-based radar system strongly favors a station-based approach. The optimum is to service the satellite in its operational orbit, but even returning the satellite to the station provides an economic benefit compared to a most favorable servicing environment from a Shuttle-base system. The comparison involves only the cost of recurring transportation and does not consider amortized costs for either a Shuttle, the OTV, or the space station itself. As discussed earlier, several satellites are available for servicing and an estimated 3 to 6 servicing missions per year is well within reasonable bounds. A significant 10-year savings can be realized, which demonstrates the benefits of a station-based system compared to a Shuttle-based system.

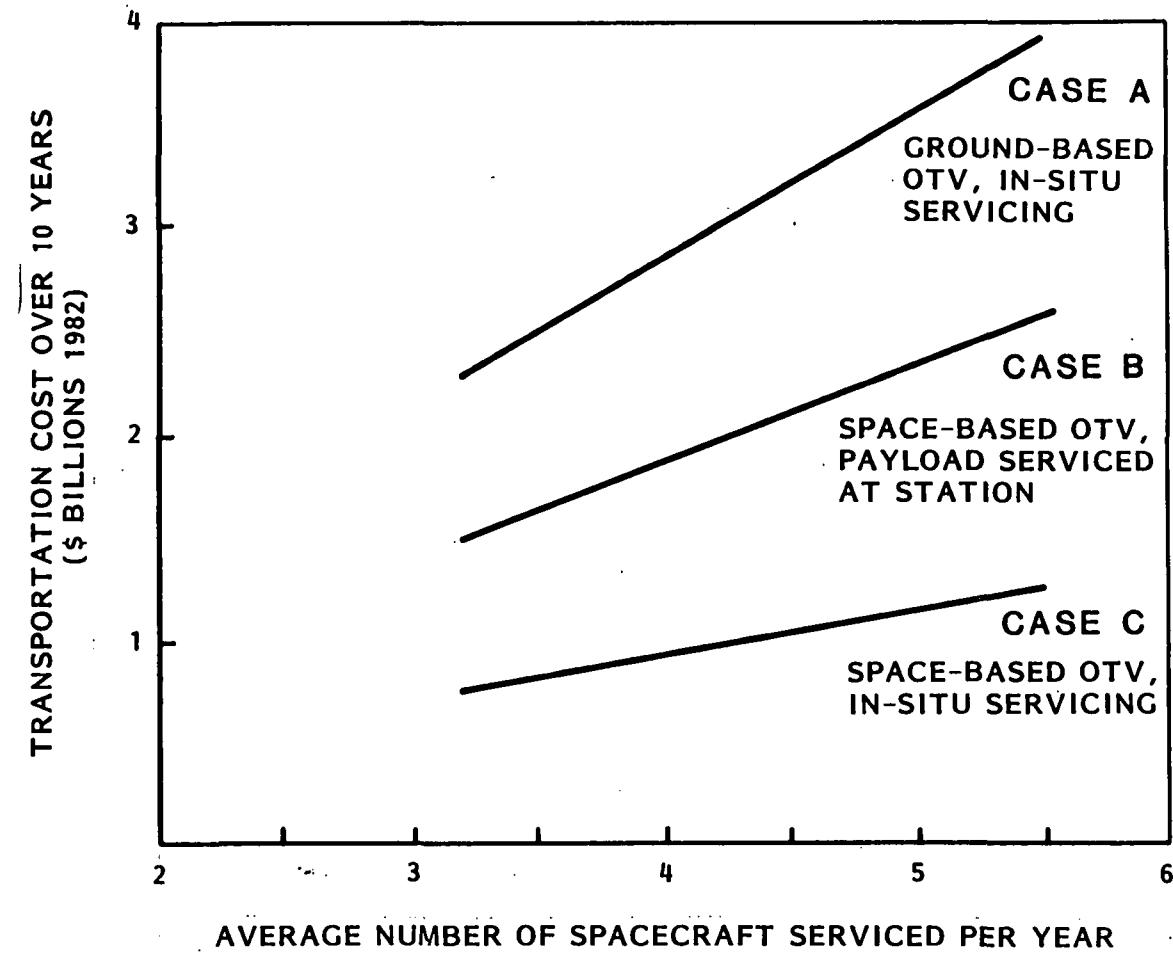




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## GROUND-BASED VS STATION-BASED OTV SERVICING

(COST OF RECURRING TRANSPORTATION)



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## SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

THESE MISSION SCENARIOS HAVE BEEN SELECTED TO COVER THE FIVE CATEGORIES OF SPACE OPERATIONS

### ON-BOARD OPERATIONS

1- HARD DOCKED PAYLOADS, CAPTIVE FREE-FLYER, AND TETHERED SATELLITES

- o LARGE STRUCTURES ASSEMBLY (LARGE ANTENNA FOR SPACE RADAR)
- o ASTRONOMY PLATFORM SUPPORT (TETHERED)

### REMOTE OPERATIONS

2- SUPPORT OF SATELLITES IN LOCAL STATION VICINITY

- o ASTRONOMY PLATFORM SUPPORT (AS A FREE-FLYER)

3- SUPPORT OF SATELLITES IN NEARBY INCLINATIONS AT NODAL COINCIDENCE

- o SPACE TELESCOPE MAINTENANCE
- o SPACE BASED RADAR (ITSS) MAINTENANCE

4- UNIVERSAL SUPPORT OF LEO SATELLITES

- o PROMPT SATELLITE REPLACEMENT
- o SHUTTLE CREW RESCUE VEHICLE

5- UNIVERSAL SUPPORT OF GEO SATELLITES

- o GEO SATELLITE RESUPPLY

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## APPROACHES TO REPLACEMENT OF OPERATIONAL NATIONAL SECURITY SATELLITE

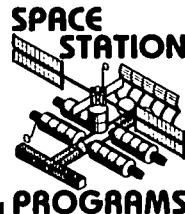
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An operational concern for the space-based radar system is the procedure for replacing a satellite in the constellation if it should fail. Prompt replacement (within a matter of days) is required to keep the system fully functional and thus the minimum energy transfer at nodal coincidence is generally not possible from a space station base.

Three options are outlined on this and following pages. The current approach is to use a ground launch for a spare satellite since access to any orbit is available on a minimum energy basis within a day's notice. Also, ground basing keeps the system in a controlled environment and allows update and checkout before launch. Only one spare satellite is required to replace any failed satellite in the system.

Another option is to keep dormant spares in operational inclination and altitude, but this has the disadvantage that a spare satellite must be available in each plane within a given inclination, which significantly increases spares cost. Also, these satellites are not accessible for update and checkout before operation. Another approach is to keep a dormant spare at very high altitude and return it to operational altitude when required. Although only one spare is required to replace any satellite in the system, the inaccessibility for checkout and update, combined with the substantial energy required to place the satellite initially and to return it when desired, makes this approach a less attractive. The space-station-based approach is discussed in the following pages.





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## APPROACHES TO REPLACEMENT OF OPERATIONAL NATIONAL SECURITY SATELLITE

### 1. GROUND LAUNCH OF SPARE SATELLITE (CURRENT ITSS SBR APPROACH)

- ADVANTAGES:
- NO CONSTRAINT ON PLACEMENT TO OPERATIONAL ORBIT
  - SPARE KEPT ON GROUND - UPDATE AND CHECKOUT ARE FACILITATED
  - ONE SPARE CAN REPLACE ANY SATELLITE IN SYSTEM

- DISADVANTAGES:
- SHUTTLE MANIFEST MAY CONSTRAIN REPLACEMENT RESPONSE
  - IMMEDIATE RESPONSE CAPABILITY WOULD REQUIRE DEDICATED ELV
  - LAUNCH SITE IS VULNERABLE IN TIME OF CRISIS OR WAR

### 2. CO-ORBITAL DORMANT SPARE

- ADVANTAGES:
- SPARE IS AT OPERATIONAL ALTITUDE AND INCLINATION
  - COPLANAR MANEUVER CAN EASILY CORRECT PHASING  
( $\Delta V \sim 1000$  FT/SEC)

- DISADVANTAGES:
- MUST HAVE SPARE FOR EACH ORBIT PLANE IN USE
  - CHECKOUT AND SYSTEM UPDATE DIFFICULT

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APPROACHES TO REPLACEMENT OF OPERATIONAL  
NATIONAL SECURITY SATELLITE (CONT)

By storing the satellite at the space station, checkout and equipment update can be accomplished readily. Transfer at nodal coincidence is generally not possible; significant energy is therefore required to place the dormant satellite in its operational orbit. However, existing OTVs can be used for this purpose even with satellites as large as the ITSS space-based radar. The propellant required to make this transfer is significant, but it is feasible to provide this capability. The advantage of a space-based launch versus a ground-based launch may make this approach attractive for certain mission applications even after accounting for vulnerability and security considerations. As discussed in the section on constraints imposed by orbit mechanics, a satellite located at a station at any inclination can be boosted to any operational position for a delta V of approximately 15,000 ft/sec for a one-way transfer. As shown on the next page, it requires a small additional delta V to provide capability for the OTV to return to the space station or to a Shuttle-compatible orbit for later retrieval.





## APPROACHES TO REPLACEMENT OF OPERATIONAL NATIONAL SECURITY SATELLITE (CONT)

### 3. ON-ORBIT STORAGE OF SPARE AT SPACE STATION

- ADVANTAGES:
- NO CONSTRAINT ON PLACEMENT TO OPERATIONAL ORBIT  
( $\Delta V \sim 15,000$  FT/SEC ONE WAY;  
FOR 24,000 LB SATELLITE - 75,000 LB OF  
CRYOPROPELLANT IS REQUIRED FOR TRANSFER)
  - SPARE KEPT AT STATION;  
CHECKOUT AND SYSTEM UPDATE ARE FACILITATED
  - LAUNCH OPERATIONS POTENTIALLY LESS VULNERABLE  
THAN GROUND SITE
  - ONE SPARE CAN REPLACE ANY SATELLITE IN SYSTEM
- DISADVANTAGE:
- ONE-WAY TRANSIT USES EXPENSIVE OTV
    - COMPARABLE TO GROUND LAUNCH OF ELV
    - OTV COULD BE RECOVERED BY SHUTTLE AT  
LATER TIME

ON-ORBIT STORAGE OF SPARE SATELLITES

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The chart on the facing page shows an ITSS space-based radar satellite in the stowed configuration attached to an OTV made up of 2 Centaur-G vehicles. The mass and propellant distribution for this system are indicated on the chart and a maximum delta V capability is also shown. This system incorporates an aerobraking capability on the second-stage OTV. Up to 90,000 lb of propellant can be carried. Individual components of this system are compatible with the Shuttle orbiter.

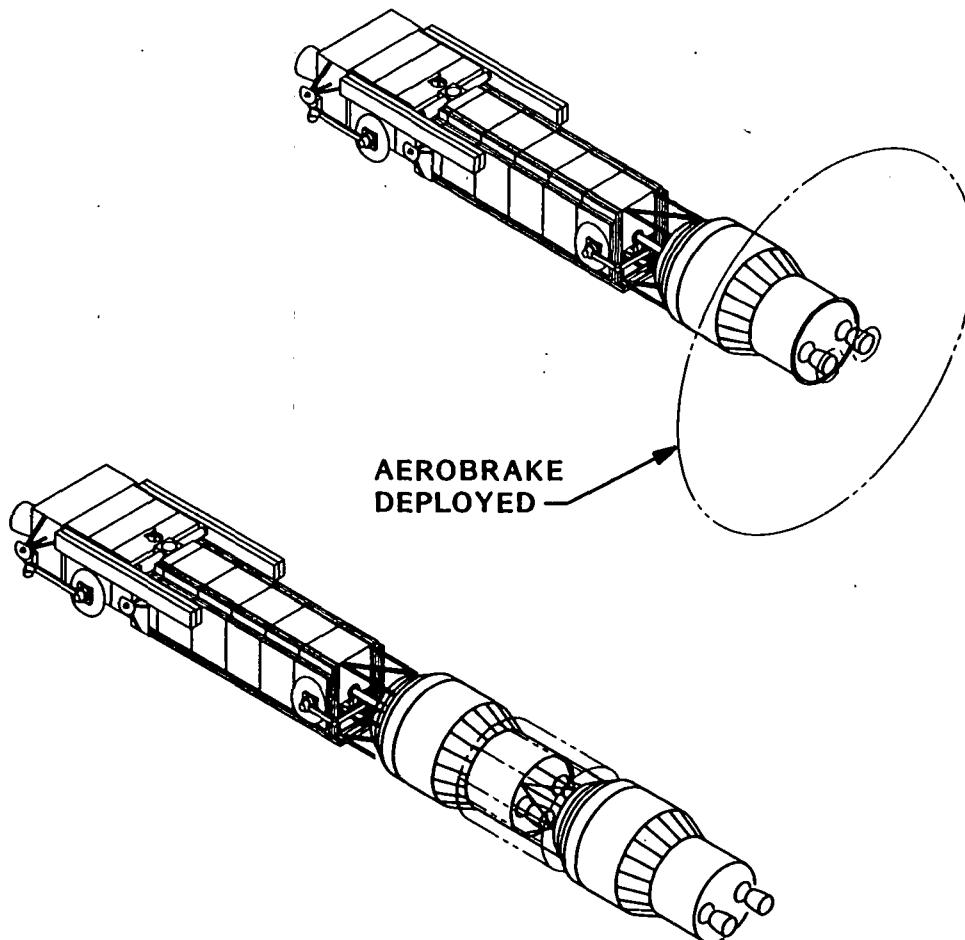




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## 24K LB SPACE BASED RADAR--ONE-WAY TRANSFER

REUSABLE CENTAUR-TYPE OTV  
CRYOGENIC PROPELLANT (ISP = 440)



AEROBRAKE  
DEPLOYED

TOTAL PROPELLANT  
(BOTH STAGES)  
90 KLB

MAXIMUM  $\Delta V$   
WITH 24,000-LB PAYLOAD  
18.0 K FPS

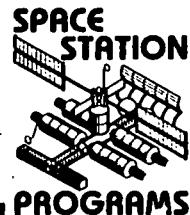
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## ON-ORBIT STORAGE OF SPARE SATELLITES (CONT)

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This chart displays a storable propellant OTV that provides capability similar to that available from the centaur combination shown on the proceeding page. A higher propellant load (115,000 lb) and a slightly lower total delta V result from the lower ISP (340) of this system compared to that for the Centaur (ISP = 440). The advantage of this system is that it is based on storable propellants that do not have insulation problems and boiloff considerations encountered with cryogens. The configuration shown can be readily built from existing flight-proven components; however, it is not an existing vehicle stage ready for flight. This configuration has been used in several studies for various satellite missions.



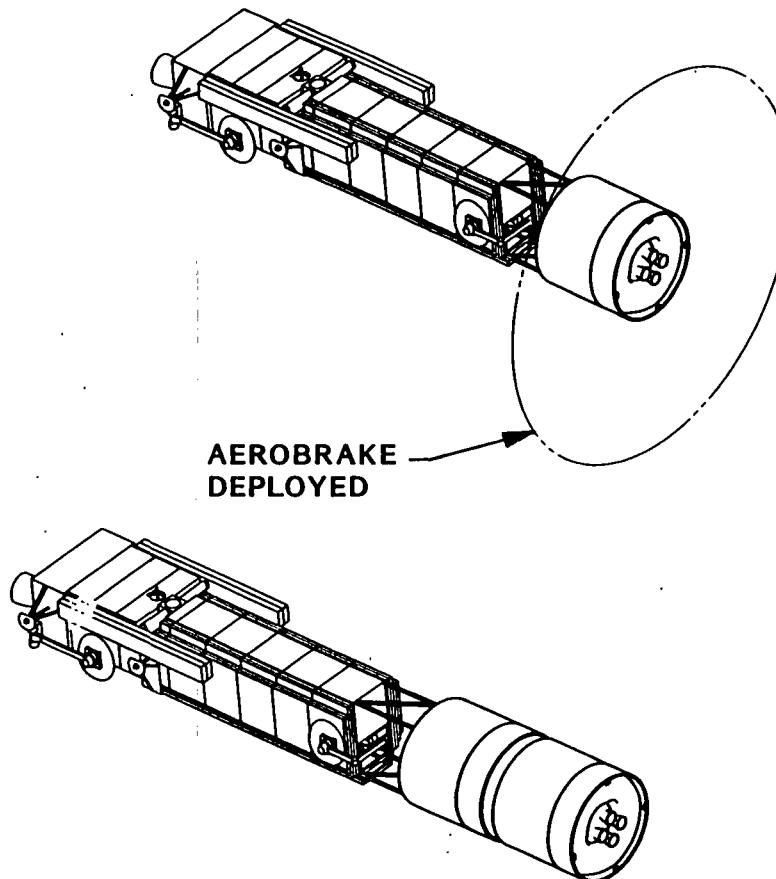


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## 24K LB SPACE-BASED RADAR - ONE-WAY TRANSFER

REUSABLE OTV STORABLE PROPELLANT (ISP = 340)

C-5



AEROBRAKE  
DEPLOYED

TOTAL PROPELLANT  
(BOTH STAGES)  
115 KLB

MAXIMUM  $\Delta V$   
WITH 24,000-LB PAYLOAD  
16.4 K FPS

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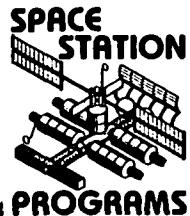
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SHUTTLE CREW RESCUE VEHICLE

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Some may question why a shuttle crew rescue mission is considered in a section on LEO satellite servicing. An orbiting shuttle is, in fact, a satellite, and crew rescue from a disabled vehicle is indeed a high priority mission, quite appropriately discussed in a section on satellite servicing.

At the present time, the only means to rescue the crew of an orbiting disabled Space Shuttle is to launch another Shuttle orbiter. Although onboard reentry rescue capsules have been considered, this approach has the disadvantage that the reentry capsule takes weight and volume away from available payload. However, the presence of the space station allows an alternative concept to be implemented in which the Shuttle crew rescue vehicle is permanently based at the space station. Several approaches have been considered in previous studies, including rescue capsules for each crewperson. The concept discussed here considers a single vehicle sized for a crew of 10. This vehicle could be boosted to any orbit with the combination of two OTVs in a fashion similar to that used for the ITSS space-based radar satellite replacement. The rescue capsule is estimated to weigh less than 24,000 lb to carry a crew of up to 10; this rescue capsule could also provide emergency support to the space station itself. The transit time will vary from 1 to 35 hours, depending on the specific location of the space station and Space Shuttle at time of use.



## SHUTTLE CREW RESCUE VEHICLE

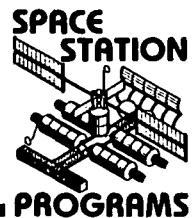
- REENTRY VEHICLE (RV) AND OTV TO BE STORED AT SPACE STATION
- RV DESIGNED FOR 10-PERSON CAPACITY
  - MAXIMUM SHUTTLE CREW IS SEVEN
  - 10-PERSON CAPACITY ALLOWS GROWTH TO SUPPORT STATION NEEDS (2 RVs, RATHER THAN ONE LARGER SIZE, USED TO SUPPORT STATION CREW TO PROJECTED SIZE OF 20 IN 1998)
- PROPER OTV (E.G., WIDE-BODY CENTAUR WITH AEROBRAKING) CAN TRANSFER RV TO ANY ORBIT FROM ANY STATION LOCATION
  - STATION AT 28.5 DEGREES COULD SUPPORT RESCUE OF ORBITER CREW EVEN AT 98 DEGREES
  - FIRST "TRUE" SAFE-HAVEN FOR ORBITER CREW
  - TRANSIT TIME IS APPROXIMATELY 35 HR
  - APPROXIMATELY 70,000 LB OF CRYOPROPELLANT REQUIRED
- RV COULD ALSO SERVE AS MANNED CREW AND CARGO TRANSFER VEHICLE

TEN-PERSON RESCUE VEHICLE

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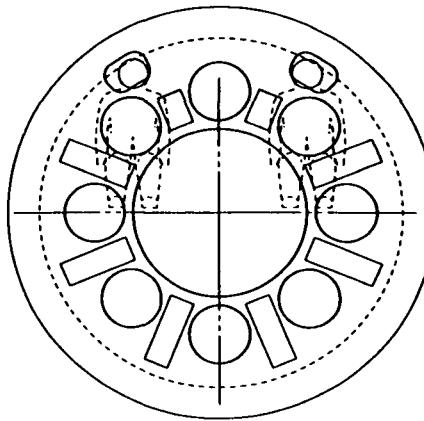
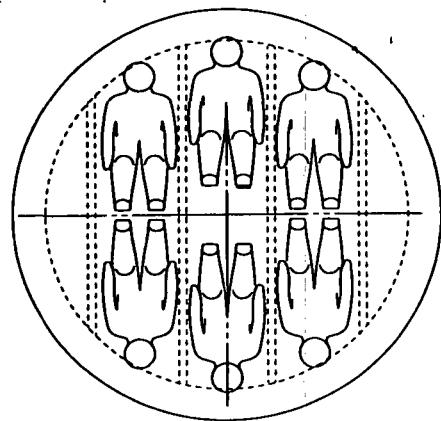
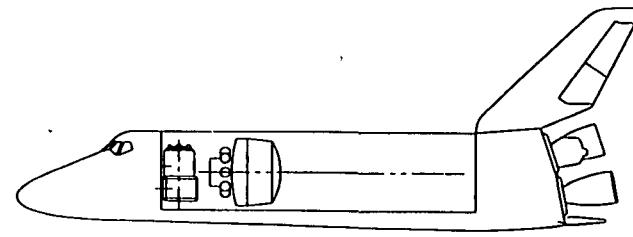
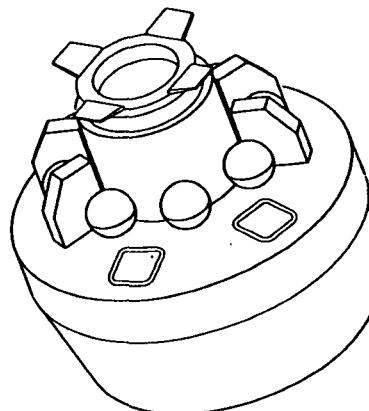
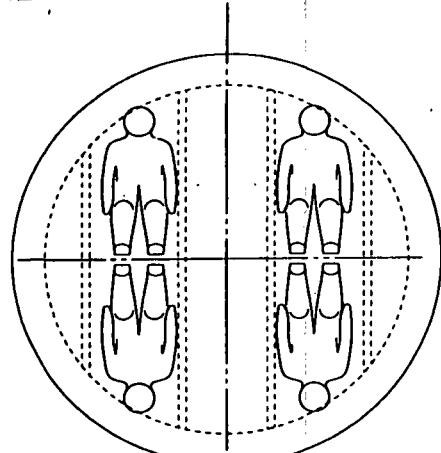
A Shuttle-compatible rescue vehicle for 10 persons is shown in the sketch on the facing page. This configuration was developed using existing technology (including an Apollo-type heat shield), providing volume for the crew and necessary consoles and equipment. No detailed design has been developed, although a preliminary estimate indicates such a system would weigh about 24,000 lb.



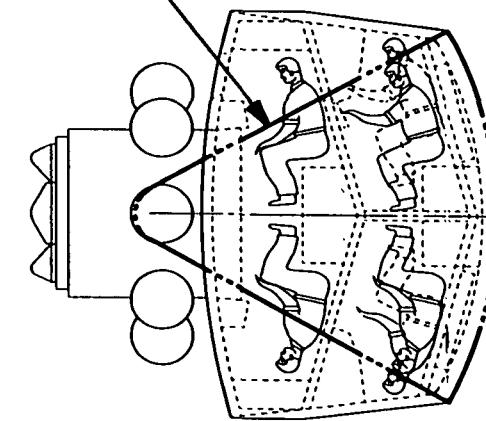


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## 10-PERSON RESCUE VEHICLE



APOLLO  
OUTLINE



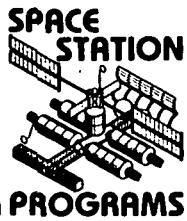
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OTV RESCUE CONCEPT

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By using two centaur OTVs in tandem with aerobraking on the second stage OTV a delta V of 18,000 feet per second can be obtained. If propellant is retained in the first and second stage to allow the first stage to return to the station and to allow the second stage to return to a 220 nautical mile orbit for later pick-up by the space shuttle, the delta V of the system is reduced to 16,500 feet per second. This is still adequate to reach any LEO position from any space station location, provided aerobraking is used as indicated.

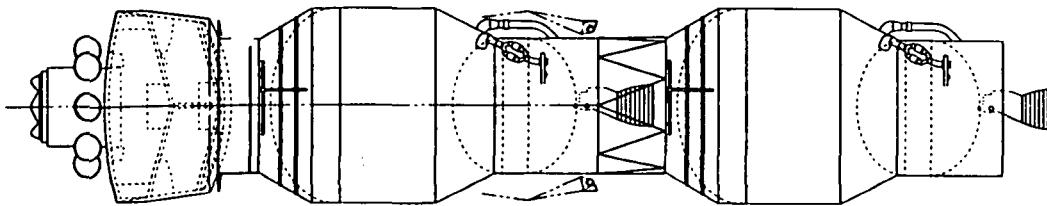




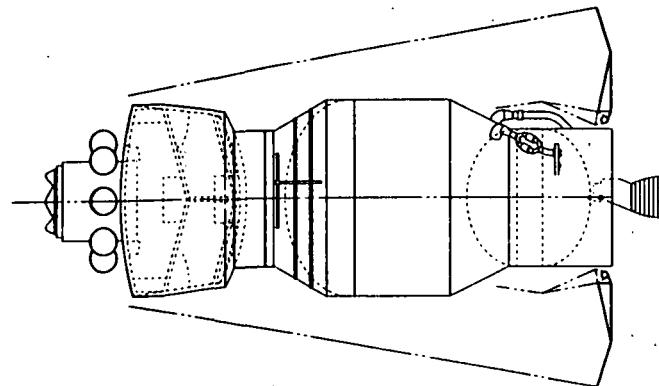
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## 24K LB PAYLOAD - ONE-WAY TRANSFER

REUSABLE CENTAUR-TYPE OTV CRYOGENIC PROPELLANT (ISP = 440)



	PAYOUT 24,000 LB	SECOND STAGE	FIRST STAGE
PAYOUT	24,000 LB		
PROPELLANT		45,000 LB	45,000 LB
INERT WEIGHT		6,640	6,640
AEROBRAKING		3,000	0
INTERSTAGE	INCL IN P/L	0	360



$\Delta V$  (K FPS)  
STAGE ASCENT RETURN

### ONE-WAY OTV

FIRST	6.0	0
SECOND	12.0	0
TOTAL	18.0	

### FIRST STAGE RETURN

FIRST	5.4	5.4
SECOND	12.0	0
TOTAL	17.4	

### BOTH STAGE RETURN\*

FIRST	5.4	5.4
SECOND	11.1	3.0
TOTAL	16.5	

\*SECOND STAGE RETURNS  
TO SHUTTLE-COMPATIBLE  
ORBIT

Lockheed

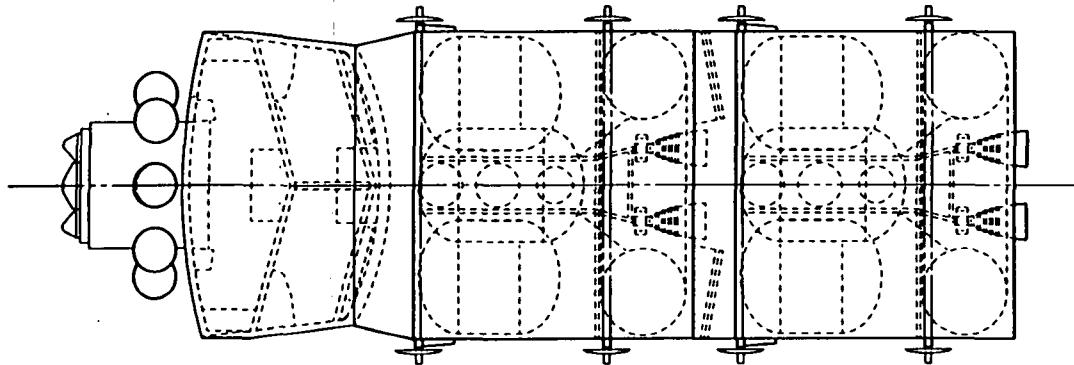
## OTV RESCUE CONCEPT (CONTINUED)

---

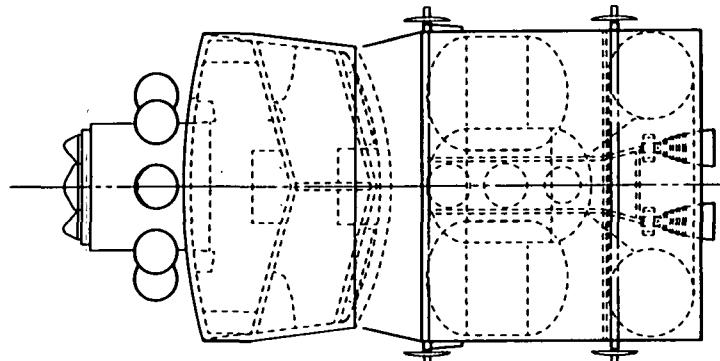
An alternative configuration using storable propellants is shown in the chart on the facing page. The propellant load has increased to 115,000 lbs and the delta V available has dropped by 1,500 feet per second, but this system still has the capability to launch to almost any location at any time. It has the advantage that the storable propellants avoid the restraints imposed by long term storage of cryogens on orbit.



# 24K LB PAYLOAD – ONE-WAY TRANSFER REUSABLE OTV STORABLE PROPELLANT (ISP=340)



	PAYLOAD	24,000 LB	SECOND STAGE	FIRST STAGE
PROPELLANT			57,570 LB	57,570 LB
INERT WEIGHT			5,080	5,080
AEROBRAKING			3,000	0
INTERSTAGE	INCL IN P/L		0	320



$\Delta V$  (KFPS)  
STAGE ASCENT RETURN

ONE-WAY OTV

FIRST	5.2	0
SECOND	11.2	0
TOTAL	16.4	

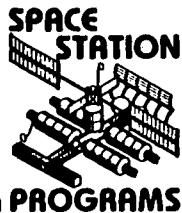
FIRST STAGE RETURN

FIRST	4.8	4.8
SECOND	11.2	0
TOTAL	16.0	

BOTH STAGE RETURN\*

FIRST	4.8	4.8
SECOND	10.4	3.0
TOTAL	15.2	

\*SECOND STAGE RETURNS  
TO SHUTTLE-COMPATIBLE  
ORBIT



## SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

THESE MISSION SCENARIOS HAVE BEEN SELECTED TO COVER THE FIVE CATEGORIES OF SPACE OPERATIONS

### ON-BOARD OPERATIONS

- 1- HARD DOCKED PAYLOADS, CAPTIVE FREE-FLYER, AND TETHERED SATELLITES
  - o LARGE STRUCTURES ASSEMBLY (LARGE ANTENNA FOR SPACE RADAR)
  - o ASTRONOMY PLATFORM SUPPORT (TETHERED)

### REMOTE OPERATIONS

- 2- SUPPORT OF SATELLITES IN LOCAL STATION VICINITY
  - o ASTRONOMY PLATFORM SUPPORT (AS A FREE-FLYER)
- 3- SUPPORT OF SATELLITES IN NEARBY INCLINATIONS AT NODAL COINCIDENCE
  - o SPACE TELESCOPE MAINTENANCE
  - o SPACE BASED RADAR (ITSS) MAINTENANCE
- 4- UNIVERSAL SUPPORT OF LEO SATELLITES
  - o PROMPT SATELLITE REPLACEMENT
  - o SHUTTLE CREW RESCUE VEHICLE
- 5- UNIVERSAL SUPPORT OF GEO SATELLITES
  - o GEO SATELLITE RESUPPLY

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The Lockheed logo consists of a stylized 'W' shape followed by the word "Lockheed".

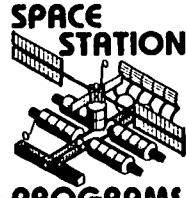
GEO SATELLITE RESUPPLY

---

A block diagram of activities required to resupply a GEO satellite is presented on the facing page. Initial satellite servicing missions for GEO satellites will likely be limited to resupply of consumables to extend system life. As capabilities for remote operations evolve, the sophistication of on-orbit servicing in GEO will grow.

Satellite systems such as MILSTAR could use the fuel resupply capability in the early stages of space station operation. The present design and system approach on existing and currently planned GEO satellites do not account for servicing. A change in approach and/or block 1 modification type effort to satellite design is required before an effective GEO satellite servicing option can be developed.

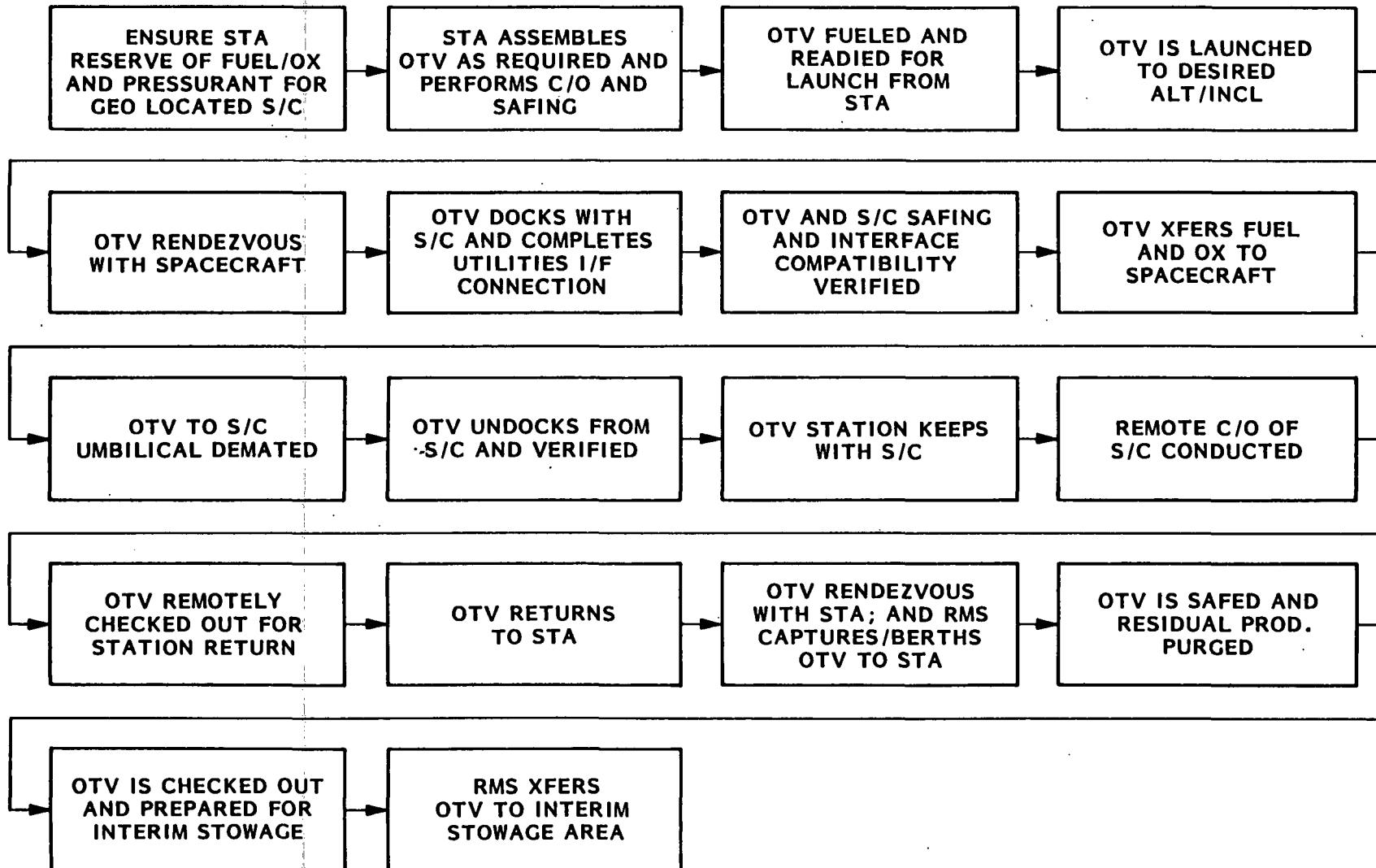




PROGRAMS

LMSC-D889718

## GEO SATELLITE RESUPPLY



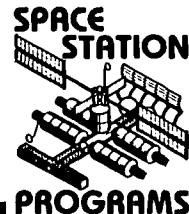
 Lockheed

OPERATIONAL SUPPORT MATRIX FOR  
GEO SATELLITE RESUPPLY

---

The use of the space station to support GEO satellite servicing imposes certain requirements on the station as shown on the facing page. These requirements are essentially identical to those imposed by satellite servicing for LEO systems and thus there are no conceptual or generic changes required to the space station for this activity. One operational constraint is that the propellant required for one-way transfer of a large payload taxes the capability of existing OTV systems. Thus a roundtrip mission can be envisioned if the payload (e.g., propellant resupply) is comparatively small. A one-way mission would be used if a payload the size of the ITSS space-based radar were to be launched to GEO.

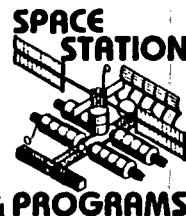




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## OPERATIONAL SUPPORT MATRIX GEO SATELLITE RESUPPLY

STATION NEEDS	OPERATIONAL SUPPORT FUNCTION							
	OTV ASSEMBLY	CHECKOUT - OTV	CHECKOUT - SIG	LAUNCH CONTROL	RMS OPS	ORB OPS	COMMAND/CONTROL	SAFEING
1. FUEL TANKAGE							●	
2. OXIDIZER TANKAGE							●	
3. PRESSURANT TANKAGE							●	
4. PROP/PRESS XFER SYS							●	
5. AIRLOCK/XFER TUNNEL	●							
6. OTV CAPTURE DEVICE			●					
7. BERTHING PLATFORM	●						●	
8. DOCKING UNIT	●						●	
9. STAGE ASSY FACILITY	●							
10. ON-BOARD C/O SYSTEM		●	●			●		
11. MANIP C/O-BASE UNIT				●				
12. EVA AIDS/XLATION TECH	●							
13. OTV AND S/C LAUNCH/ OFS CONTROL			●		●	●		



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# SUMMARY

## SPACE-BASED SPACECRAFT SERVICING

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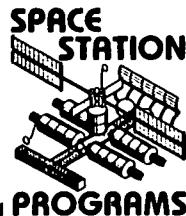
1.5-173

SPACECRAFT SERVICING AND THE SPACE STATION

---

Key considerations in spacecraft servicing as supported by the space station are indicated in the following pages. Clearly, the space station is an excellent base for satellite servicing and, even as initially configured the station can be developed as a node in the transportation system capable of supporting operational satellites designed for servicing. However, if the station is to function in this role, spacecraft must be properly designed to take advantage of benefits of on-orbit servicing.





## SPACECRAFT SERVICING AND THE SPACE STATION

- A. SPACE STATION SUPPORT FOR SCHEDULED SPACECRAFT SERVICING IS HIGHLY VIABLE
- B. SPACE STATION SUPPORT FOR SCHEDULED SPACECRAFT SERVICING IS STRONGLY INFLUENCED BY:
  - 1. SPACECRAFT ALTITUDE AND INCLINATION
  - 2. ORBITAL MECHANICS AND NODAL POINTS VS. TIME
  - 3. AVAILABILITY OF ORBITAL TRANSFER VEHICLES
  - 4. GROUND TO STATION LOGISTICS
  - 5. SERVICING LOCATION
  - 6. SPACECRAFT DESIGN FOR SERVICING
  - 7. SPARES (ORU) AVAILABILITY
  - 8. SERVICING SCHEDULES
  - 9. STAGING SUPPORT
  - 10. LEVELS OF CHECKOUT
- C. NASA AND DOD WILL HAVE TO TAKE A MORE AGGRESSIVE ROLE IN DEVELOPING SERVICEABLE SPACECRAFT FOR STATION TO BENEFIT FROM SERVICING FUNCTION

SPACECRAFT SERVICING AND THE SPACE STATION (CONT)

---

As shown on the facing page, LMSC has defined servicing from three different approaches: development of mission scenarios, evaluation of ongoing programs at LMSC, and consideration of generic servicing concepts. From these considerations for support of unscheduled spacecraft servicing, key issues were identified.





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## SPACECRAFT SERVICING AND THE SPACE STATION (CONT)

D. LMSC HAS DEFINED SERVICING FROM THREE APPROACHES:

1. TASK 1 SCENARIOS
2. LMSC PROGRAMS (HARDWARE)
3. GENERIC CONCEPTS

E. SPACE STATION SUPPORT FOR UNSCHEDULED SPACECRAFT SERVICING IS STRONGLY INFLUENCED BY:

1. ACCESSIBILITY TO SPACECRAFT
2. AVAILABILITY OF OTV
3. LOGISTICS IMPLICATIONS
4. SPARES (ORU) AVAILABILITY
5. TIMELINE FACTORS
6. CRITICALITY OF SPACECRAFT ORBITAL AVAILABILITY
7. FEASIBILITY OF ORBITAL SERVICE
8. STATION CONFIGURATION

F. NUMBER OF SPACECRAFT THAT STATION CAN SERVICE WITHOUT AN OTV OR OTHER SYSTEM IS FEW

 Lockheed

SPACECRAFT SERVICING AND THE SPACE STATION (CONT)

---

Use of the space station as a base for servicing satellites will substantially influence the architecture of the station. Key elements to be considered are listed on the facing page.



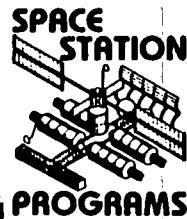


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## SPACECRAFT SERVICING AND THE SPACE STATION (CONT)

### G. SERVICING OF SPACECRAFT BY OR AT STATION SUBSTANTIALLY INFLUENCES STATION ARCHITECTURE:

1. OTV PARKING/SERVICING
2. CONSUMABLES STOWAGE/HANDLING
3. SPARES (ORU) STOWAGE
4. CHECKOUT EQUIPMENT/LOCATIONS/ACCESS
5. SERVICING HANGER
6. OTV OR SPACECRAFT APPROACH/DEPART ENVELOPES
7. DOCKING/BERTHING FACILITIES
8. RMS ACCESSIBILITY
9. SPARES (ORU) HANDLING/TRANSFER ENVELOPES
10. SPARES SPACECRAFT STOWAGE/CONDITIONING
11. UTILITIES - RUNS AND INTERFACES
12. SPACECRAFT APPENDAGE ENVELOPES



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## CONCLUSIONS

### SPACE-BASED SPACECRAFT SERVICING

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The Lockheed logo features a stylized five-pointed star or arrowhead pointing upwards and to the right, positioned to the left of the company name.

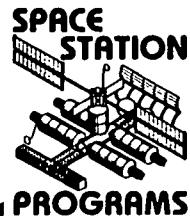
1.5-181

## KEY TECHNOLOGY ISSUES FOR STATION-BASED SATELLITE SERVICING

---

Several technology issues require attention during development of the space station. These issues are highlighted on the facing page. There are no technological problems that would prevent the use of space station for satellite servicing. Exploration and development of the concepts shown in this section will greatly benefit, however, from further advances in the technologies shown on the facing page. A few areas (OTV Aerobraking, Crew Rescue Vehicle) require significant development activity before certain missions can be considered for space station.





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## KEY TECHNOLOGY ISSUES FOR STATION-BASED SATELLITE SERVICING

- DESIGN OF SPACECRAFT FOR SERVICING
- SERVICING HARDWARE DEVELOPMENT
- DESIGN FOR ON-ORBIT REFUELING
  - SHUTTLE DEMONSTRATION
  - SATELLITE/OTV DEMONSTRATION
- DEVELOPMENT OF REUSABLE OTV
- DEVELOPMENT OF OTV AEROBRAKING SYSTEM
  - AERO THERMO DYNAMICS
  - STRUCTURES
  - MATERIALS
  - G & C
- DEVELOPMENT OF DEBRIS CAPTURE/HANDLING HARDWARE
- DEVELOPMENT OF 10-MAN REENTRY VEHICLE



CONCLUSIONS

---

The space station will provide a beneficial and cost-effective support base for on-orbit servicing of spacecraft and payloads. Note that existing OTVs have the capability to support space-based servicing, even for missions requiring transfer of large payloads through trajectories involving substantial delta V. The space station is an excellent base for storing dormant satellites for launch on short notice to replace operational satellites that have failed. The station is also an excellent base for supporting a Shuttle crew rescue vehicle which will enhance the overall safety of the Space Shuttle system.

Consideration of spacecraft servicing requirements must be given careful attention in the early phases of space station design to ensure that proper capability is developed for this important function. Of equal importance, however, is the need to design spacecraft so they can be serviced on-orbit from either space station or Space Shuttle .



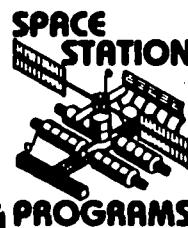


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## CONCLUSIONS

1. SPACE STATION CAN PROVIDE A BENEFICIAL AND COST-EFFECTIVE FUNCTION IN SPACECRAFT AND PAYLOAD SERVICES
2. CONSIDERABLE TECHNOLOGY AND ASSOCIATED APPROACHES EXIST FOR DESIGN OF SPACECRAFT FOR ON-ORBIT SERVICING/MAINTENANCE
3. DESIGN FOR ON-ORBIT MAINTENANCE IS GENERALLY NOT CONSIDERED EARLY ENOUGH IN THE PROGRAM IMPLEMENTATION CYCLE
4. PRIMARY CONCERN IN DESIGN FOR MAINTENANCE IS STANDARDIZATION
5. THE ISSUE OF 'SPARES' CONTINUES TO BE A PROGRAM LEVEL PROBLEM
6. IT IS NOT TOO EARLY TO BEGIN DEVELOPING AN ORBITAL MAINTENANCE CONCEPT(S) FOR SPACE STATION





## **TASK 1—MISSION REQUIREMENTS**

- 1.1 USER ALIGNMENT PLAN**
- 1.2 SCIENCE AND APPLICATIONS**
  - PHYSICAL SCIENCES
  - LIFE SCIENCES
- 1.3 COMMERCIAL**
- 1.4 U.S. NATIONAL SECURITY**
- 1.5 SPACE OPERATIONS**
- 1.6 REQUIREMENTS FROM USER NEEDS**
- 1.7 FOREIGN CONTACTS**

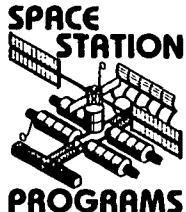
 Lockheed

REQUIREMENTS SOURCES

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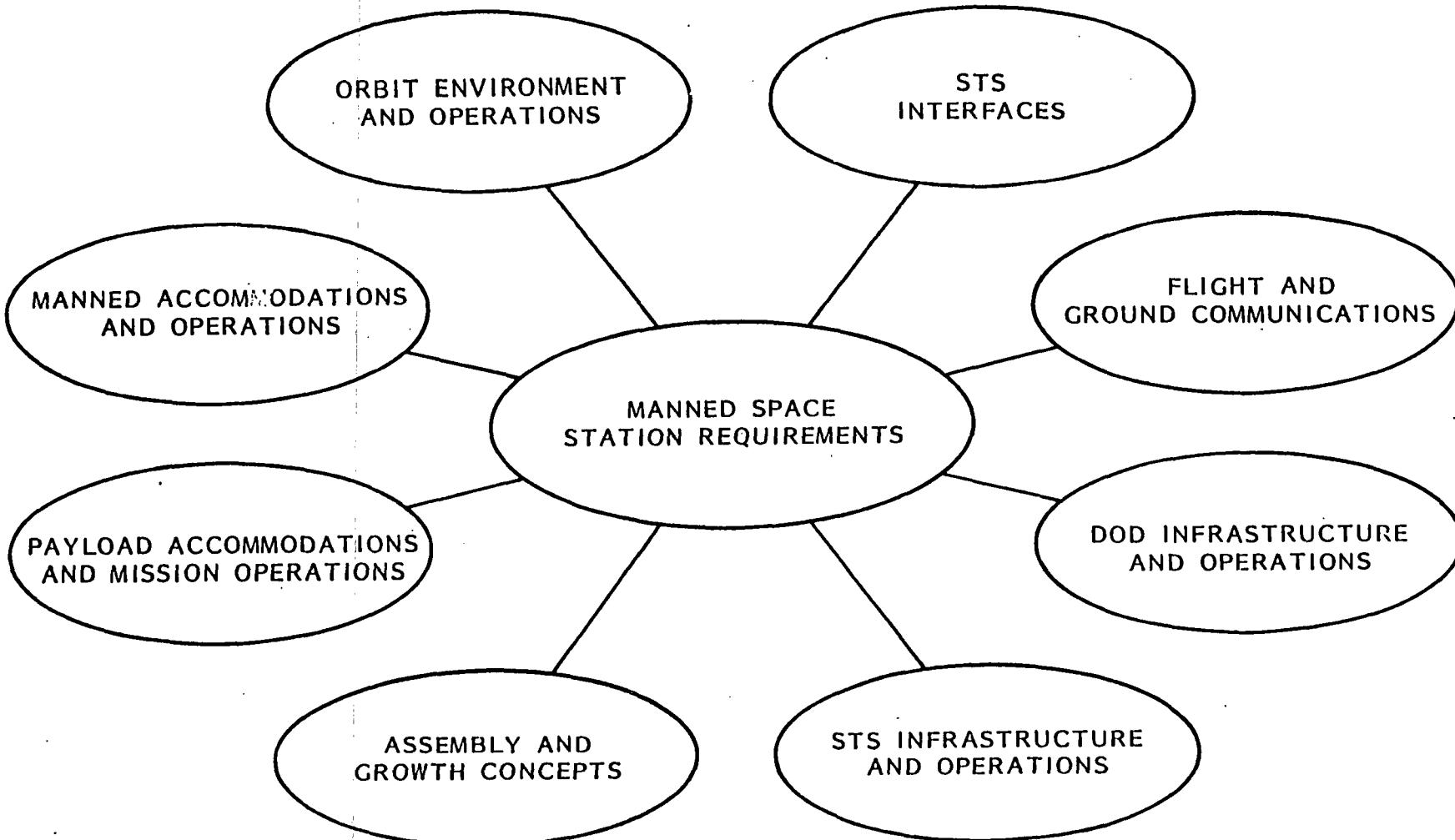
The primary source of Space Station of requirements is the user needs. Requirements are also imposed by the nature of operations to be conducted and by the infrastructure elements with which the station must interface. The chart on the right illustrates source categories of requirements. These categories cover both the requirements that are imposed on the station itself, and those that result from interfaces with the STS elements flight and ground communications, etc.





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## REQUIREMENTS SOURCES



REQUIREMENTS DEFINITION

---

Definition of user requirements was initially based on the existing data base. This source of information, though limited, was useful in the science and applications area.

New, up to date sources of user requirements were necessary in all areas, but particularly in the commercial, national security and operations categories. Extensive personal contacts with users generated some, but a very limited number of "hard requirements" for the space station. For this reason specific mission scenarios were developed to provide a focus for definition of specifics. This approach was the most fruitful in terms of defining specific requirements from user needs.





## REQUIREMENTS DEFINITION

- EXISTING DATA BASE
- USER CONTACTS
- MISSION SCENARIO DEVELOPMENT

## MANNED SPACE STATION FUNCTIONS

---

Our user contacts resulted in a set of functions that must be accomplished by a manned space station either on the station itself or on a station controlled platform/free flyer. It is the functions that must be performed that determine requirements. The adjacent chart lists those broad categories of functions that lead to requirements.





## MANNED SPACE STATION FUNCTIONS

- SUPPORT FOR LONG DURATION PAYLOADS THAT NEED DIRECT MANNED INTERVENTION
- SUPPORT MANNED SPACECRAFT THAT NEED PERIODIC MANNED INTERVENTION  
(ASSEMBLY, EXPERIMENT CHANGEOUT)
- ORBIT PLACEMENT AND RECOVERY OF PAYLOADS
- SUPPORT ORBIT STAGING, LAUNCH AND RECOVERY OF FREE FLYERS
- TEST BED FOR DEVELOPMENT OF SENSORS, TECHNIQUES, SUPPORT SYSTEMS
- LOGISTICS SUPPORT INTERFACE WITH STS

## BASIC SPACE STATION FUNCTIONAL REQUIREMENTS

---

Based on our extensive contacts with potential Space Station users, a number of functional requirements surfaced. While these are general in nature they tended to be brought up frequently and must be considered to be prerequisites for any Space Station concept or architectural configuration.





## SPACE STATION FUNCTIONAL REQUIREMENTS

SPACE STATION MUST PROVIDE FOR:

- PERMANENT MANNED HABITATION
- CAPABILITY FOR LONG DURATION, LOW EARTH ORBIT OPERATIONS
- ON ORBIT STATION ASSEMBLY VIA STS INTERFACE
- ON ORBIT LOGISTICS SUPPORT VIA STS
- DATA TRANSFER/COMMUNICATION LINKS WITH ORBIT-TO-ORBIT AND ORBIT-TO-GROUND INTERFACES
- CAPABILITY TO SUPPORT PAYLOADS (MULTI DISCIPLINE, PERIODIC AND CONTINUOUS OPERATIONS)
- CAPABILITY FOR GROWTH (FUNCTIONS AND OPERATIONS)
- COMPATIBILITY WITH STS INFRASTRUCTURE
- COMPATIBILITY WITH DOD INFRASTRUCTURE

NASA DATA BASE INPUT-1

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This data was submitted to LaRC as part of the LMSC Input to NASA's data base.



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1.6-10



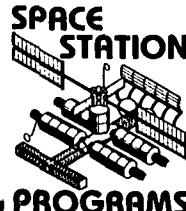
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## NASA DATA SHEET INPUT (1)

Page 1 of 3

PAYLOAD ELEMENT NAME EARTH OBSERVATION FACILITY		CODE L M S C 0 0 0 6	TYPE <input checked="" type="checkbox"/> Science & Applications (non-commercial) <input type="checkbox"/> Commercial <input type="checkbox"/> Technology Development <input type="checkbox"/> Operations Type Number <u>2</u> (see Table A) Importance of the Space Station to this Element 1 = low value but could use 10 = vital Scale 1 - 10 <u>7</u>	
CONTACT Name Address	M. Duke NASA-JSC Houston	J. Koltenback NASA- JSC Houston		
Telephone <u>(713) 483-4464</u>		<u>(713) 483-3611</u>		
STATUS				
<input type="checkbox"/> Operational <input type="checkbox"/> Approved		<input type="checkbox"/> Planned <input type="checkbox"/> Candidate <input checked="" type="checkbox"/> Opportunity		
First flight, yr <u>1990</u>				
No. of flights <u>  </u>				
Duration of Flight, days <u>1800</u>				
OBJECTIVE Observation of Earth on a continuous long-term basis - Detection and monitoring of geodetic characteristics, thermal absorption and radiation characteristics, and status of renewable and nonrenewable material resources.				
DESCRIPTION A research and development objective is to evaluate role of man in an operational environment and to evaluate effectiveness of new sensing and analysis techniques. Sensors and equipment to be mounted on pallets, capable of continuous operations, capability to pre-program viewing and to interact in real time accurate track and target location correlation required, real time data transmission to control (space) station.				

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## NASA DATA SHEET INPUT (2)

Page 2 of 3

ORBIT CHARACTERISTICS			
Apogee, km	600	Perigee, km	400
Inclination, deg	57	Tolerance +	-
Nodal Angle, deg		Tolerance +	-
Escape dV Required, m/s		Ephemeris Accuracy, m	
POINTING/ORIENTATION			
View direction	<input type="checkbox"/> Inertial	<input type="checkbox"/> Solar	<input checked="" type="checkbox"/> Earth
Truth Sites (if known)			
Pointing accuracy, arc sec	Field of view, deg		
Pointing Stability (Jitter)arc sec/sec			
Special Restrictions (Avoidance)			
POWER			
<input type="checkbox"/> AC	<input checked="" type="checkbox"/> DC	Power, W	Duration, hrs/day
Operating	6 KW		
Standby			
Peak			
Voltage, V	Frequency, Hz		
DATA/COMMUNICATIONS			
Monitoring requirements:			
<input type="checkbox"/> None	<input checked="" type="checkbox"/> Realtime	<input type="checkbox"/> Offline	<input type="checkbox"/> Other
<input type="checkbox"/> Encryption/Decryption Required			
<input type="checkbox"/> Uplink Req./Command Rate (KBS)	Frequency (MHZ)		
<input checked="" type="checkbox"/> On-Board Data Processing Required			
Description			
Computer pre-process capability			
Data Types:	<input type="checkbox"/> Analog	<input type="checkbox"/> Digital	<input type="checkbox"/> Hrs/Day
Film (Amount)		Voice (Hrs/Day)	
Live TV (Hrs/Day)		Other	
On-Board Storage (MBIT)			
Data Dump Frequency (Per Orbit)			
Recording Rate (KBPS)		Downlink Frequency (MHZ)	

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## NASA DATA SHEET INPUT (3)

Page 3 of 3

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<b>THERMAL</b>																						
<input type="checkbox"/> Active <input type="checkbox"/> Passive																						
Temperature, deg C	operational min _____ max _____ non-operational min _____ max _____																					
Heat Rejection, w	operational min _____ max _____ non-operational min _____ max _____																					
<b>EQUIPMENT PHYSICAL CHARACTERISTICS</b>																						
Location:	<input type="checkbox"/> Internal <input checked="" type="checkbox"/> External <input type="checkbox"/> Remote																					
Equipment ID/Function	<input type="checkbox"/> Pressurized <input type="checkbox"/> Unpressurized																					
L,m	7.6 W,m 4.3 H,m _____																					
L,m	W,m H,m _____																					
Launch mass, kg	5000																					
Consumables Types	_____																					
Acceleration sensitivity, g	min _____ max _____																					
<b>CREW REQUIREMENTS</b>																						
Crew Size	2																					
Skills (See Table B)	Task Assignment    TBD																					
	<table border="1"><tr><td>SKILL</td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr><tr><td>LEVEL</td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr><tr><td>Hrs/Day</td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr></table>	SKILL							LEVEL							Hrs/Day						
SKILL																						
LEVEL																						
Hrs/Day																						
EVA	<input type="checkbox"/> YES <input type="checkbox"/> NO																					
Reason _____ Hrs/EVA _____																						
<b>SERVICING/MAINTENANCE</b>																						
SERVICE Interval, days	TBD																					
Returnables, kg	Consumables, kg _____																					
<b>CONFIGURATION CHANGES</b> Interval, day _____																						
Deliverables, kg	TBD Man Hours _____ Man/Hrs Req. _____ Returnables, kg _____																					
<b>SPECIAL CONSIDERATIONS</b> See Instructions																						
The facility will use a 10.6m synthetic aperture radar (SAR) with L-and C-band and L- and X-band capability. A planar phased array antenna (11m x 2.1m) will be used in conjunction with the radar electronic and data electronics.																						
The facility will also use an imaging spectrometer (IS) fed by a 3m telescope mounted on a pointing mount for fine guidance and pointing.																						

MISSION SUPPORT REQUIREMENTS

---

Each Space Station mission scenario was analyzed to determine requirements that might be readily accomplished on the Space Station. From these requirements were developed the Mission Support Requirements, i.e., the capability the space station would need to provide in order to successfully fulfill the mission requirements. In many cases these support requirements have been included in the scenarios contained in Attachment 2, Volume 1.

This series of 14 charts list the principal drivers that will influence space station architecture - crew size, power requirements, support, environment, EVA and manned interaction as well as orbit parameters. Based on these drivers and needs identified by users, generic types of space stations were established for each of the missions ('scenarios'). These ranged from manned modules to attached laboratories and platforms, both attached and free flying. These broadly identified requirements were an input to Task 2, Mission Implementation Concepts in which space station architectural concepts were developed.





PROGRAMS

## MISSION SUPPORT REQUIREMENTS - SCIENCE

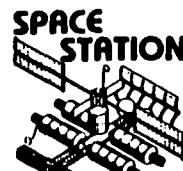
MISSION SS SUPPORT CAPABILITY	LIFE SCIENCES HUMAN RESEARCH LABORATORY	LIFE SCIENCES NON-HUMAN RESEARCH LABORATORY	CELESTIAL OBSERVATORY	SPACE ENVIRONMENT FACILITY
SENDER PLATFORM ATTACHED	ATTACHED SHIRTSLEEVE LAB MODULE	ATTACHED LAB MODULE W/ PLANT/ANIMAL VIVARIA	ATTACHED PALLET, REMOTE MONITOR	ATTACHED PALLETS, REMOTE MONITOR
TETHER OR FREE FLYER			POSSIBLE	POSSIBLE
LIFETIME	10 YEARS	10 YEARS	10 YEARS	10 YEARS
ORBIT	28.5° 300 KM	28.5° 300 KM	28.5° 300 - 400 KM	57° 400 KM
POINTING	N/A	N/A	SOLAR, IPS SLEW RATE 180° - 5 MIN.	SOLAR, EARTH LIMB, RADAR & MAGNETIC FIELD POINTING
POWER	4 KW	8 KW	1.4 KW (AVE)	10KW



## MISSION SUPPORT REQUIREMENTS - SCIENCE (CONTINUED)

MISSION SS SUPPORT CAPABILITY	LIFE SCIENCES HUMAN RESEARCH LABORATORY	LIFE SCIENCES NON-HUMAN RESEARCH LABORATORY	CELESTIAL OBSERVATORY	SPACE ENVIRONMENT FACILITY
LOGISTICS SUPPORT	90 DAY LAB SUPPLIES AND CONSUMABLES	90 -180 DAYS LAB SUPPLIES AND CONSUMABLES		
REFUELING	N/A	N/A	N/A	N/A
ORBIT ASSEMBLY	INTACT DELIVERY	INTACT DELIVERY	INTACT DELIVERY	SENSOR ADDITION/ RETRIEVAL
CHECKOUT	N/A	N/A		YES
CREW SIZE	2 EXPERIMENTERS 4 CREW MEN SUBJ.	2 EXPERIMENTERS	2 EXPERIMENTERS	2 EXPERIMENTERS
EVA	N/A	N/A	PERIODIC	PERIODIC
LOW G ENVIRONMENT	YES - FOR PERIODIC TEST	N/A	N/A	N/A

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## MISSION SUPPORT REQUIREMENTS - SCIENCE (CONTINUED)

MISSION SS SUPPORT CAPABILITY	LIFE SCIENCES HUMAN RESEARCH LABORATORY	LIFE SCIENCES NON-HUMAN RESEARCH LABORATORY	CELESTIAL OBSERVATORY	SPACE ENVIRONMENT FACILITY
LABORATORY ENVIRONMENT	YES	VIVARIA FOR ANIMAL/PLANTS	REMOTE CONTROL & MONITOR	REMOTE CONTROL & MONITOR
DATA PROCESSING	ON-BOARD, REAL TIME	ON-BOARD	ON-BOARD, REAL TIME, FILM AND TELEMETRY	ON-BOARD REAL TIME, FILM AND TELEMETRY
COMMUNICATIONS	PERIODIC TO GROUND	PERIODIC TO GROUND	TO GROUND, TDRSS	TO GROUND, TDRSS
MANNED INTERACTION	YES-REAL TIME	YES	YES-REAL TIME TARGETING	YES-REAL TIME REMOTE
EXPERIMENT/MODULE REPLACEMENT	CREW REPLACEMENT 90 DAYS	SPECIMEN CHANGE 90 - 180 DAYS	CONTAMINATION CONTROL MEASURES	CONTAMINATION CONTROL MEASURES

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## MISSION SUPPORT REQUIREMENTS - SCIENTIFIC APPLICATIONS (CONTINUED)

MISSION SS CAPABILITY	EARTH OBSERVATION FACILITY	GLOBAL HABITABILITY OBSERVATORY LABORATORY
SENSOR PLATFORM, ATTACHED	ATTACHED PALLET, REMOTE MONITOR	ATTACHED PALLET, REMOTE MONITOR
TETHER OR FREE FLYER	POSSIBLE	POSSIBLE
LIFETIME	5 - 10 YEARS	10 YEARS
ORBIT	57°, 400 - 600 KM	57°, 300 KM
POINTING	EARTH VIEWING, IPS FOR ACCURACY	EARTH VIEWING, IPS FOR ACCURACY
POWER	6 KW	7 KW
LOGISTICS SUPPORT	90 DAYS LAB SUPPLIES	90 DAYS LAB SUPPLIES
REFUELING	N/A	N/A
ORBIT ASSEMBLY	INTACT DELIVERY, ATTACH SENSORS	INTACT DELIVERY, ATTACH SENSORS

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## MISSION SUPPORT REQUIREMENTS - SCIENTIFIC APPLICATIONS (CONTINUED)

MISSION SS CAPABILITY	EARTH OBSERVATION FACILITY	GLOBAL HABITABILITY OBSERVATORY LABORATORY
CHECKOUT		
CREW SIZE	2 EXPERIMENTERS	4 EXPERIMENTERS
EVA	PERIODIC	PERIODIC
LOW G ENVIRONMENT	NOT REQUIRED	NOT REQUIRED
LABORATORY ENVIRONMENT	REMOTE CONTROLS AND MONITOR IN SHIRT SLEEVE ENVIRONMENT	REMOTE CONTROLS AND MONITOR IN SHIRT SLEEVE ENVIRONMENT
DATA PROCESSING	ON-BOARD, REAL TIME ANALYSIS	ON-BOARD, REAL TIME ANALYSIS
COMMUNICATIONS	REAL TIME TO GROUND	REAL TIME TO GROUND
MANNED INTERACTION	MONITOR, REAL TIME TARGETING	MONITOR, REAL TIME TARGETING CONTINUOUS
EXPERIMENT/MODULE REPLACEMENT	PERIODIC	PERIODIC

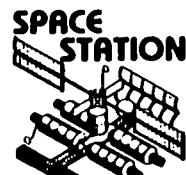


## MISSION SUPPORT REQUIREMENTS - COMMERCIAL

MISSION SS CAPABILITY	MATERIAL PROCESSING RESEARCH LABORATORY	MATERIAL PROCESSING OPERATIONS FACILITY
SENSOR PLATFORM, ATTACHED		
DETACHED, TETHER OR FREE FLYER	LAB MODULE UNCOUPLED FROM HABITATION MODULE FOR LOW GRAVITY EXPERIMENTATION	PROCESSING LAB MODULE EXTENDED TIME FREE FLYER WITH PERIODIC MANNED PRESENCE
LIFETIME	3 - 6 YEARS	5 - 10 YEARS
ORBIT	ANY	CLOSE PROXIMITY TO SPACE STATION
POINTING	N/A	INERTIAL ORIENTATION
POWER	5 - 10 kW	15 kW
LOGISTICS SUPPORT	90 DAYS LAB SUPPLIES AND CONSUMABLES	3-6 MONTHS SUPPLIES, WEEKLY PERSONNEL FROM SPACE STATION

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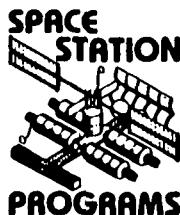


PROGRAM:

## MISSION SUPPORT REQUIREMENTS - COMMERCIAL (CONTINUED)

MISSION SS CAPABILITY	MATERIAL PROCESSING RESEARCH LABORATORY	MATERIAL PROCESSING OPERATIONS FACILITY
REFUELING	NOT APPLICABLE	ALTITUDE CONTROL AND ORBIT MAINTENANCE EXPENDABLES
ORBIT ASSEMBLY	SPECIMEN BUILD-UP AND ASSEMBLY	PRODUCTION HARDWARE INSTALLATION
CHECKOUT		FACILITY ACTIVATION-PERIODIC MAINTENANCE AND VERIFICATION
CREW SIZE	2 - 4 OPERATORS	2 - 4 OPERATORS
EVA	AS REQUIRED	AS REQUIRED
LOW G ENVIRONMENT	CONTINUOUS DURING EXPERIMENTS	CONTINUOUS DURING PRODUCTION
LABORATORY ENVIRONMENT	SHIRT SLEEVE, HANDS-ON	SHIRT SLEEVE, HANDS-ON
DATA PROCESSING	ON-BOARD, REAL TIME	ON-BOARD, REAL TIME
COMMUNICATIONS	TO GROUND, NON-REAL TIME	TO GROUND, PERIODIC, NON-REAL TIME

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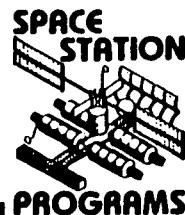


## MISSION SUPPORT REQUIREMENTS - COMMERCIAL (CONTINUED)

MISSION SS CAPABILITY	MATERIAL PROCESSING RESEARCH LABORATORY	MATERIAL PROCESSING OPERATIONS FACILITY
MANNED INTERACTIONS	REAL TIME, EXPERIMENT SET UP, DATA EVALUATION	REAL TIME DURING PRODUCTION SET UP
EXPERIMENT/MODULE REPLACEMENT	SAMPLE REPLACEMENT REQUIRED FOR EXTENDED TIME PERIODS	AS REQUIRED FOR MAINTENANCE AND CHANGE OF PRODUCTION

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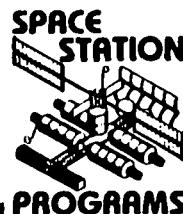


## MISSION SUPPORT REQUIREMENTS - U. S. NATIONAL SECURITY

MISSION SS CAPABILITY	OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LABORATORY	ORBITING NATIONAL COMMAND POST	SPACE OBJECTS IDENTIFICATION SYSTEM
SENSOR PLATFORM, ATTACHED	ATTACHED PALLETS		MODULE ATTACHED
TETHER OR FREE FLYER	POSSIBLE FOR SENSORS	COMMAND/HABITATION MODULE IN EXTERNAL TANK STRUCTURE	
LIFETIME	10 YEARS	10 YEARS	10 YEARS
ORBIT	57°, 300-700 KM	28.5°, 550-750 KM	ANY
POINTING	EARTH VIEWING, IPS FOR PRECISION	EARTH ATTITUDE ORIENTATION	EARTH
POWER	5 KW	15 KW NUCLEAR SOURCE	7 KW
LOGISTICS SUPPORT	90 DAYS LAB SUPPLIES AND CONSUMABLES	90 DAYS SUPPLIES AND PERSONNEL ROTATION	90 DAYS SUPPLIES AND CONSUMABLES

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## MISSION SUPPORT REQUIREMENTS - U. S. NATIONAL SECURITY (CONTINUED)

MISSION SS CAPABILITY	OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LABORATORY	ORBITING NATIONAL COMMAND POST	SPACE OBJECTS IDENTIFICATION SYSTEM
REFUELING	N/A	DRAG MAKE-UP, 300 LB/YEAR	N/A
ORBIT ASSEMBLY	ATTACH PALLETS, ATTACH SENSORS	EXTERNAL TANK MODS, INSTALL COMMAND/ HABITATION MODULES, NUCLEAR POWER	ATTACH MODULES TO SPACE STATION
CHECKOUT	N/A	ON-BOARD CAPABILITY	MODULE CAPABILITY
CREW SIZE	2	12 MIXED	4 MIXED
EVA	PERIODIC	PERIODIC FOR SERVICING	AS REQUIRED
LOW G ENVIRONMENT	N/A	N/A	NOT REQUIRED

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## MISSION SUPPORT REQUIREMENTS - U. S. NATIONAL SECURITY (CONTINUED)

MISSION S S CAPABILITY	OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LABORATORY	ORBITING NATIONAL COMMAND POST	SPACE OBJECTS IDENTIFICATION SYSTEM
LABORATORY ENVIRONMENT	PERSONNEL IN SHIRT SLEEVE ENVIRONMENT	SHIRT SLEEVE WORKING ENVIRONMENT-CONSOLES	SHIRT SLEEVE WORKING ENVIRONMENT
DATA PROCESSING	ON-BOARD, REAL TIME ANALYSIS	ON-BOARD, REAL TIME, VISUAL & PRINT OUT	ON-BOARD, REAL TIME
COMMUNICATIONS	REAL TIME TO GROUND	AIR TO AIR, AIR TO GROUND, SECURE DATA LINKS, REAL TIME	AIR TO AIR, AIR TO GROUND, SECURE DATA LINKS, REAL TIME
MANNED INTERACTIONS	YES, ACQUISITION DATA COMPARISON CORRELATION	MONITOR CONSOLES, CONTINUOUS OPERATIONS	TARGETING, MONITOR SENSORS, EVALUATE DATA
EXPERIMENT / MODULE REPLACEMENT	WILL BE REQUIRED TO EVALUATE NEW SYSTEMS	SCHEDULED / UNSCHEDULED MAINTENANCE	AS REQUIRED

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## MISSION SUPPORT REQUIREMENTS - U. S. NATIONAL SECURITY (CONTINUED)

MISSION S S CAPABILITY	OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LABORATORY	ORBITING NATIONAL COMMAND POST	SPACE OBJECTS IDENTIFICATION SYSTEM
LABORATORY ENVIRONMENT	PERSONNEL IN SHIRT SLEEVE ENVIRONMENT	SHIRT SLEEVE WORKING ENVIRONMENT-CONSOLES	SHIRT SLEEVE WORKING ENVIRONMENT
DATA PROCESSING	ON-BOARD, REAL TIME ANALYSIS	ON-BOARD, REAL TIME, VISUAL & PRINT OUT	ON-BOARD, REAL TIME
COMMUNICATIONS	REAL TIME TO GROUND	AIR TO AIR, AIR TO GROUND, SECURE DATA LINKS, REAL TIME	AIR TO AIR, AIR TO GROUND, SECURE DATA LINKS, REAL TIME
MANNED INTERACTIONS	YES, ACQUISITION DATA COMPARISON, CORRELATION	MONITOR CONSOLES, CONTINUOUS OPERATIONS	TARGETING, MONITOR SENSORS, EVALUATE DATA
EXPERIMENT/ MODULE REPLACEMENT	WILL BE REQUIRED TO EVALUATE NEW SYSTEMS	SCHEDULED/ UNSCHEDULED MAINTENANCE	AS REQUIRED

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## MISSION SUPPORT REQUIREMENTS - SPACE OPERATIONS

MISSION S S CAPABILITY	SATELLITE SERVICING LEO	ON-ORBIT STRUCTURAL ASSEMBLY
SENSOR PLATFORM, ATTACHED	ATTACHED PALLETS	ATTACHED PALLETS
DETACHED, TETHER OR FREE-FLYER		PLATFORM ATTACHED TO SPACE STATION
LIFETIME	10 YEARS	5 - 10 YEARS
ORBIT	28 1/2°, 400 KM	28 1/2°, 400 KM
POINTING	N/A	N/A
POWER	10 KW	10 KW
LOGISTICS SUPPORT	90-180 DAYS SUPPLIES AND CONSUMABLES	AS REQUIRED, SUPPLIES AND CONSUMABLES
REFUELING	AS REQUIRED FOR ATTITUDE CONTROL AND ORBIT MAINTENANCE	AS REQUIRED FOR ATTITUDE CONTROL AND ORBIT MAINTENANCE

 Lockheed



## MISSION SUPPORT REQUIREMENTS - SPACE OPERATIONS (CONTINUED)

S S CAPABILITY	MISSION SATELLITE SERVICING LEO	ON-ORBIT STRUCTURAL ASSEMBLY
ORBIT ASSEMBLY	ATTACH PALLETS, MODULES, ON-ORBIT REPLACEMENT	ASSEMBLE STRUCTURES, SATELLITES
CHECKOUT	ON-BOARD CAPABILITY	ON-BOARD CAPABILITY
CREW SIZE	2 - 10	10
EVA	YES	YES
LOW G ENVIRONMENT	NOT REQUIRED	NOT REQUIRED
LABORATORY ENVIRONMENT	SHIRT SLEEVE WORKING ENVIRONMENT	SHIRT SLEEVE
DATA PROCESSING	ON-BOARD, REAL TIME, PRINT OUT	ON-BOARD, REAL TIME, PRINT OUT
COMMUNICATIONS	AIR TO AIR, REAL TIME TO GROUND	AIR TO AIR, REAL TIME TO GROUND



## MISSION SUPPORT REQUIREMENTS - SPACE OPERATIONS (CONTINUED)

MISSION S S CAPABILITY	SATELLITE SERVICING LEO	ON-ORBIT STRUCTURAL ASSEMBLY
MANNED INTERACTION	YES, CHECKOUT, REPAIR, MAINTENANCE.	YES, ASSEMBLY AND CHECKOUT
EXPERIMENT/MODULE	SCHEDULED, UNSCHEDULED MAINTENANCE AND REPAIR	AS REQUIRED

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SPACE STATION EVOLUTION

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Following the establishment of mission support requirements based on user contacts, mission implementation concepts were formulated for a four phase space station evolution. A modest capability was planned for 1990 with an expanded capability station in the late 1990's. An overview of this phasing is shown in the adjacent chart. Subsequent charts define each phase, the details of which provided ground rules for completing tasks 2 and 3.

The evolution was developed within guidelines that required staying rather general in trade studies and avoiding point design while still driving towards detailed user needs. General needs may be summarized as lower inclinations, LEO, general purpose initial station capability (due in part to a lack of specific knowledge of space environments), adaptability to an unknown real future, and a user friendly station.





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## SPACE STATION EVOLUTION

### SPACE STATION-PHASE IV

TIME	MISSION	SPACE STATION SERVICES	IMPACTS AND OPTIONS	COMMENTS AND CONSIDERATIONS
1988	DOD OPERATIONS	EXPANDED C <sup>3</sup> I ESCAPE CAPSULE	NUCLEAR POWER IUDI THRUST PROPULSION	MAY INCLUDE MAIN STATIONS IN CRITICAL ORBITS WITH SMALL OUTPOST STATION EQUALLY SPACED
2000	C & C	LARGE CREW HARDENING	SHIELDING TO-LOCATED DEFENSE	

### SPACE STATION-PHASE III

TIME	MISSION	SPACE STATION SERVICES	IMPACTS AND OPTIONS	COMMENTS AND CONSIDERATIONS
1995	INSTALLING & SERVICING	CAPABILITY TO TRANSFER	MAIN LEO STATION &	MAINTENANCE SCHEDULE WILL ESTABLISH VISITS

### SPACE STATION-PHASE II

TIME	MISSION	SPACE STATION SERVICES	IMPACTS AND OPTIONS	COMMENTS AND CONSIDERATIONS
1993	SATELLITE SERVICING	DOCKING FOR: SPACESHIP	ENCLOSED OR OPEN HANGERS & WORK PLATFORMS	HOW MUCH EVA CAN BE EXPECTED - WILL ENCLOSED WORK STATIONS BE REQUIRED?
1994	OTV SERVICING	OTV TMS	EXTENT OF TESTING OF OTV/	TE TANK FARM ON ARCE LASER BATTLE

### SPACE STATION-PHASE I

TIME	MISSION	SPACE STATION SERVICES	IMPACTS AND OPTIONS	COMMENTS AND CONSIDERATIONS
1990	SCIENCE & APPLICATION EXPERIMENTS	HABITAT	NUCLEAR OR SOLAR POWER	MUST BE CAPABLE OF USING EITHER SOL OR NUC PERHAPS TIME PHASED
	DOD RE D COMMERCIAL PROCESSING EXPERIMENTS	POWER	SEPARATE MANNED LAB	INTERNAL LAUNCH SENSOR VIEWING/PORTS ACCESS TO SPACE
	OPERATIONAL EXPERIENCE	EXPERIMENT SUPPORT	FIXED EXPERIMENT PALLET	MAN TENDED
		COMMUNICATIONS	ISOLATED EXPERIMENT PALLET	ISOLATED PALLET REQUIREMENTS PROBABLY SATISFIES THE PHASE I BY LOCALLY IDENTIFIED PROJECT
		ENVIRONMENT	SEPARATE OR INTEGRAL C & DH CAPSULE	USE OF ESA SPACE LAB EUREKA
	ZERO G			HOW CAN ELECTRONICS BE UPDATED OR REPAIRED - IN ORBIT OR GROUND
	LOW CONTAMINATION		EMERGENCY SHELTER	HOW LONG? SHOULD IT HAVE A RE-ENTRY CAPABILITY - (SHUTTLE DISASTER)

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 Lockheed

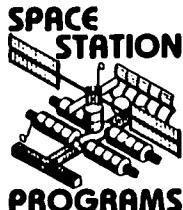
SPACE STATION EVOLUTION PHASES

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Evolution of the space station system from an initial capability in 1990 to a significantly expanded capability ten years later has been divided into four generalized phases which characterize what the station system is capable of doing at points in time. Initially the station will begin with a single shuttle launch which will provide enough hardware to implement an R&D in space facility that can accomodate civil and DoD needs. This facility will be further enhanced by additional launches. A second phase adds propulsive capability by means of TMS and/or OTV's which allows satellite servicing and our orbit assembly of larger structures to commence. A third phase expands the stations capability to handle deployment, retrieval and servicing of satellites in virtually all low or medium orbit locations. The fourth phase, near the end of the decade expands both commercial and DoD capabilities. It could then include rescue vehicles and possibly multiple stations.

Evolution of the system though the four phases shown here will be accomplished though several steps of station implementation. Later in the presentation evolutionary steps are referred to in Task 2 discussions of architectural development. Those steps, many in number, show how station implementation meets the capabilities of the four evolutionary station phases.





## EVOLUTION PHASES

### PHASE I

R&D LABORATORY - ACCOMMODATES DOD AND COMMERCIAL USER AND SCIENCE EXPERIMENTS

### PHASE II

ADDS OTV AND TMS CAPABILITY WHICH ALLOWS SUPPORT TO FREE FLYERS, SATELLITE SERVICING AND ASSEMBLY IN ORBIT

### PHASE III

EXPANDS DEPLOYMENT AND SERVICING TO LARGE MULTI-SATELLITE SYSTEMS IN ALL LEO AND HEO APPLICATIONS

### PHASE IV

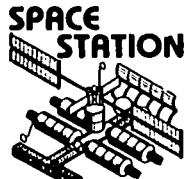
EXPANDS COMMERCIAL, DOD OPERATIONS (C2) AND RESCUE VEHICLE. COULD BE MULTIPLE STATIONS

SPACE STATION PHASE I

---

An initial space station consisting of a habitat and power module with experiment support, communications, and low g and low contamination meets the Phase I needs and missions. Configuration options are shown as well as pertinent comments and additional considerations.





PROGRAMS

## SPACE STATION PHASE I

TIME	MISSION	SPACE STATION	OPTIONS	COMMENTS AND CONSIDERATIONS
1990	SCIENCE & APPLICATION EXPERIMENTS	HABITAT POWER	NUCLEAR OR SOLAR POWER	MUST BE CAPABLE OF USING EITHER SOL OR NUC. PERHAPS TIME PHASED
	DOD R&D COMMERCIAL PROCESSING EXPERIMENTS	EXPERIMENT SUPPORT	SEPARATE MANNED LAB	INTERNAL LAUNCH SENSOR VIEWING / PORTS ACCESS TO SPACE
	OPERATIONAL EXPERIENCE	COMMUNICATIONS ENVIRONMENT ZERO G LOW CONTAMINATION	FIXED EXPERIMENT PALLET ISOLATED EXPERIMENT PALLET SEPARATE OR INTEGRAL C&DH CAPSULE EMERGENCY SHELTER	MAN TENDED ISOLATED PALLET REQUIREMENTS PROBABLY SATISFIES PHASE I BY LOOSELY TETHERED PALLET USE OF ESA SPACE LAB, EUREKA HOW CAN ELECTRONICS BE UPDATED OR REPAIRED - IN ORBIT OR GROUND? HOW LONG? SHOULD IT HAVE A RE-ENTRY CAPABILITY - (SHUTTLE DISASTER)



SPACE STATION PHASE II

---

With the advent of satellite servicing in the 1993 time period, additional station capability is required to provide for docking, fueling, and increased crew size and workload. Options are also included.





## SPACE STATION PHASE II

TIME	MISSION	SPACE STATION	OPTIONS	COMMENTS AND CONSIDERATIONS
1993	SATELLITE SERVICING	DOCKING FOR: SPACECRAFT OTV TMS	ENCLOSED OR OPEN HANGERS & WORK PLATFORMS	HOW MUCH EVA CAN BE EXPECTED - WILL ENCLOSED WORK STATIONS BE REQUIRED?
	OTV SERVICING	FUELING OTV TMS	EXTENT OF TESTING OF OTV/TMS/SPACE- CRAFT/FACILITIES FOR ASSEMBLY	WHAT STORAGE VOLUME FOR SPARES?
1994	ASSEMBLY ORBIT	REASONABLE REST AND RECREATION MODULE	CRYOGENICS - CENTRAL TANK STORAGE OR INDIVIDUAL REPLACEABLE OTV TANKS	WHAT IS REQUIREMENT FOR LOCAL MANNED TRANSPORTATION
	TMS SERVICING		INTEGRAL OR SEPARATED TANK FARM  USE OF EXTERNAL TANK AS LARGE CREW LOUNGE, STORAGE MODULE	WHAT IS HAZARD RANGE WITH EXPLOSION OF FUEL?

SPACE STATION PHASE III

---

In 1995 the capability to transfer or launch satellites to higher earth orbit from the station and to service satellites in non co-planar orbit requires additional space station components as well as transportation vehicles. The increased maneuvering capability necessitates tank farm capability to relieve pressure of servicing entirely from the shuttle.





## SPACE STATION PHASE III

### PROGRAMS

TIME	MISSION	SPACE STATION	OPTIONS	COMMENTS AND CONSIDERATIONS
1995	INSTALLING & SERVICING OF LARGE MULTI-SATELLITE SYSTEMS IN LEO, MEO & ECCENTRIC ORBITS  STORAGE OF SPACECRAFT IN QUICK LAUNCH MODE	CAPABILITY TO TRANSFER TO HIGH ORBIT  MANEUVERABILITY TO VISIT SATELLITES SEQUENTIALLY IN ORBIT  LARGE SCALE FUEL STORAGE & TRANSFER  STORAGE & MAINTENANCE OF SPACECRAFT FOR QUICK LAUNCH	MAIN LEO STATION & SMALL OUTPOST STATIONS  TRANSLATION VEHICLES FOR STATION COMPONENTS  MOTV FOR LATER TRANSPORTATION	MAINTENANCE SCHEDULE WILL ESTABLISH MANEUVERING REQUIREMENT. PROBABLY ONE TO TWO YEAR VISITS  EFFECT OF SEPARATE TANK FARM ON SERVICING E.G. LARGE LASER BATTLE STATIONS



SPACE STATION PHASE IV

---

Phase IV of the space station evolution results in expanded capability, larger crew, autonomous support of remote platforms, and high thrust propulsion. This capability will be needed near the turn of the century.





## SPACE STATION PHASE IV

TIME	MISSION	SPACE STATION	OPTIONS	COMMENTS AND CONSIDERATIONS
1998	DOD OPERATIONS	EXPANDED CSI	NUCLEAR POWER HIGH THRUST PROPULSION SHIELDING CO-LOCATED HARDENING	MAY INCLUDE MAIN STATIONS IN CRITICAL ORBITS WITH SMALL OUTPOST STATION EQUALLY SPACED
2000	C & C SURVEILLANCE AWACS EARLY WARNING	ESCAPE CAPSULE LARGE CREW INCREASED MANEUVERABILITY FULLY AUTONOMOUS SUPPORT OF OUTPOST STATIONS		

CAPABILITY GROWTH

---

Space station capability growth based on the phasing described in the previous charts is depicted here. This growth is based on a 10 year development span (input to the study) and progresses in a logical sequence over that period. As the study progressed and details were developed in the Mission Implementation Concepts (Task 2), we found we could accelerate the capability growth to achieve the "ultimate" space station by the 1996 to 1997 time period and still stay within the 'strawman" program funding.





## CAPABILITY GROWTH

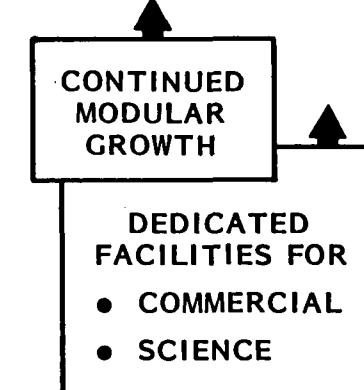
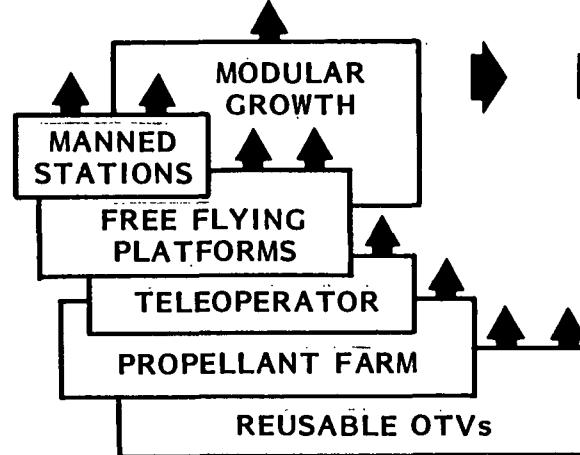
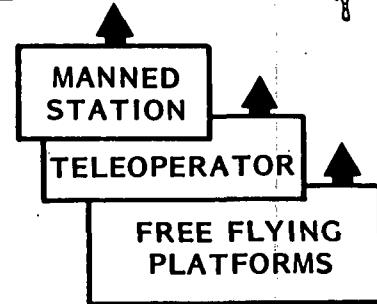
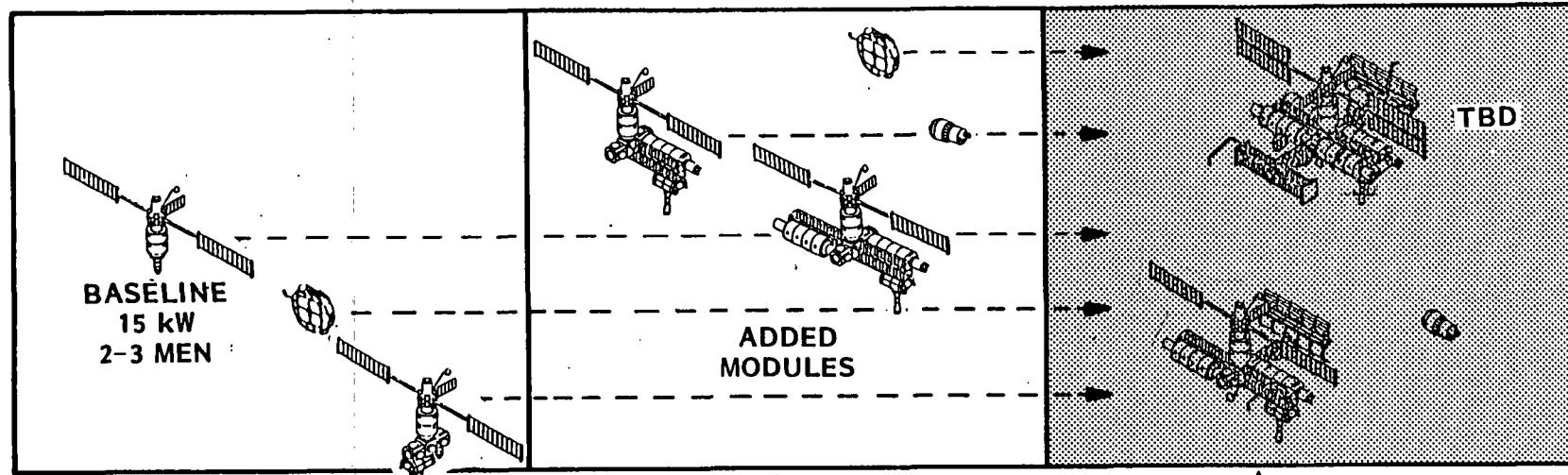
1990

INITIAL CAPABILITY

EVOLUTION

ADVANCED CAPABILITY

2000



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## CONCLUSIONS - MISSION REQUIREMENTS

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User needs alone resulted in requirements defined to a lesser extent than originally anticipated. For this reason specific scenarios were generated to provide a focus sufficient to provide good definition. This approach together with comprehensive operations analyses showed that the functions that must be performed by the space station have a greater impact on defining requirements than the mission themselves. Also, it was determined that operations are the strongest design driver.

It can readily be concluded that OTV's, an essential part of servicing, logistics, assemblies, and potentially rescue, are crucial to the space station system infrastructure.

Implementation of the station to serve virtually all users satisfactorily in the initial stage leads to a simple 2-3 person crew size, with as little as 15 kW of power in a 28.5 deg inclined orbit.

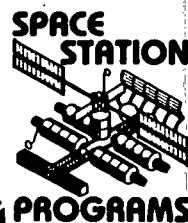
The process of mission and systems of requirements definition, flow down and allocation is a process requiring continual analysis and updating.





## CONCLUSIONS MISSION REQUIREMENTS

- SPACE STATION FUNCTIONS DICTATE REQUIREMENTS MORE THAN MISSIONS
- OPERATIONS ARE MOST SIGNIFICANT DESIGN DRIVER
- OTV'S ARE ESSENTIAL ELEMENT OF SPACE STATION
  - EXISTING OTV'S WILL PROVIDE AN IMMEDIATE CAPABILITY FOR CERTAIN MISSIONS
  - ADVANCED OTV'S WILL SIGNIFICANTLY EXPAND CAPABILITY FOR REMOTE (TELEOPERATOR ACTIVITIES)
- INITIAL STATION IMPLEMENTATION:
  - POWER 13 - 15 KW
  - 2-3 PERSONS
  - 28.5° INCLINATION
  - SINGLE SHUTTLE LAUNCH



## **TASK 1—MISSION REQUIREMENTS**

- 1.1 USER ALIGNMENT PLAN**
- 1.2 SCIENCE AND APPLICATIONS**
  - PHYSICAL SCIENCES
  - LIFE SCIENCES
- 1.3 COMMERCIAL**
- 1.4 U.S. NATIONAL SECURITY**
- 1.5 SPACE OPERATIONS**
- 1.6 REQUIREMENTS FROM USER NEEDS**
- 1.7 FOREIGN CONTACTS**

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The Lockheed logo features a stylized arrow pointing upwards and to the right, followed by the word "Lockheed" in a bold, italicized serif font.

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### WHY VISIT FOREIGN CONTACTS

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The tremendous cost of a space station relative to any single country's financial capability necessitates a cooperative effort. Furthermore, the awakening of third nation space consciousness and their proprietary views of space also call for cooperation and sharing of space station results.

In December 1982, we visited a number of European companies engaged in space work.





## WHY VISIT FOREIGN CONTACTS

- PART OF CONTRACT REQUIREMENTS
- EUROPEANS AND JAPANESE VERY ACTIVE IN SPACE EFFORT
- MANY THIRD NATIONS ALSO HAVE SHOWN INTEREST IN SPACE
- IMPROVE INTEREST AND INVESTMENT BASE OF SPACE STATION SYSTEM



FOREIGN INFORMATION EXCHANGE

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Four foreign companies signed agreements. SPAR of Toronto sent an engineer to work with us on the space station for 2 weeks. With the Europeans we have an information exchange agreement, dependent upon State Department approval.

The European visit covered a broad range of companies, research institutes and government facilities. All of these have been involved in space exploration for some time; and they presently are engaged in numerous space research/flight projects.





## FOREIGN INFORMATION EXCHANGE

AGREEMENTS AT NO COST WERE FORMALIZED WITH:

SPAR	-	TORONTO, CANADA
GTS	-	LONDON, ENGLAND
MBB/ERNO	-	BREMEN - GERMANY
DORNIER	-	FRIEDRICHSHAFEN - GERMANY

VISITS MADE 6 TO 23 DECEMBER 82:

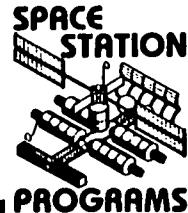
ESA	-	PARIS
ONERA	-	PARIS
MAX PLANCK INSTITUTE	-	MUNCHEN
MBB/ERNO	-	MUNCHEN AND BREMEN
DORNIER	-	FRIEDRICHSHAFEN
ERNO	-	BREMEN
DFVLR	-	KOLN
FOKKER	-	SCHIPHOL
GTS	-	LONDON
TNO	-	DELFT
ESTEC	-	NOORDWYK

FOREIGN VISIT FINDINGS

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Throughout these visits the Europeans had a unanimously enthusiastic behavior towards the prospects of a space station. However, without exception they stated a desire to be more involved than just as nuts and bolts manufacturers. They feel that being given the responsibility for a total space station subsystem would be more in line with their technical capability.





## FOREIGN VISIT FINDINGS

- EUROPEANS ENTHUSIASTIC ABOUT SPACE STATION
- FINDINGS OF ESA STUDY ABOUT SAME AS LOCKHEED STUDY
- EUROPEANS WANT RESPONSIBILITY FOR TOTAL S.S. SUBSYSTEM
- CAPABLE AND WILLING TO BUILD ANY PART OF SPACE STATION

RECOMMENDATIONS FOR FOREIGN COOPERATIVES

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The majority of contacts would like to have more responsibility. For instance, the responsibility for a total subsystem should be given to one or a group of countries. This will give the small member countries a chance to participate in space exploration with a space station.

Maybe America should look into a real cooperative partnership with the Europeans, Japanese, and others in space station development.

This type of project would lend itself very well to a partnership or venture approach. Realizing the problems that NASA would have with this type of arrangement, it is suggested that a commercial group/company be installed between NASA and the venture member countries.





## RECOMMENDATIONS FOR FOREIGN COOPERATIVES

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- CREATE TRULY INTERNATIONAL SPACE STATION
- VENTURE COUNTRIES WITH SPECIFIC TALENTS
- EACH COUNTRY RESPONSIBLE FOR A COMPLETE PART OR SUBSYSTEM
- INTEGRATION AND LAUNCH PERFORMED BY AMERICAN PARTNER
- SPACE STATION COULD BE BUILT AT AN EARLIER DATE
- FINANCIAL BURDEN LESS FOR U.S.A.



## CONCERNS ABOUT FOREIGN COOPERATIVES

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With Murphy's law in force, it is only logical that there also are concerns about a Cooperative venture with many nations as partners. However, many of these concerns are the same ones we would have with a multi-company arrangement. The large multi-national corporations have been operating for years with excellent results.

Although the concerns stated here are real, they can be overcome with effective management and a strong desire to attain the planned goal.





## CONCERNS ABOUT FOREIGN COOPERATIVES

- MANY POLITICAL AND NATIONAL BARRIERS
- COULD TURN OUT LIKE VANGUARD
- COUNTRY PULL-OUT WOULD INCREASE BURDEN FOR AMERICA
- CONTROL OVER TOTAL SPACE STATION PROJECT DILUTED

FOREIGN PARTICIPATION

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To make the space station a truly international venture methods of allocating mission functions and dividing subsystems have to be devised. These subsystem separations must not let the total space station be put at risk. The most extensive and beneficial participation by other nations will be gained by including their top-priority mission and technology objectives. Contributions by other states should emphasize:

- o Their leading technologies,
- o A nation's patented or proprietary processes, designs, and hardware or software,
- o Areas where they are giving top priority and committing substantial resources to forging breakthroughs and developing new markets, or
- o Areas where they are anxious to broaden their technical base or enhance prestige in selected fields of science.

To minimize interference among the basic space station and auxiliary missions, whether foreign or domestic, the following principles will help:

- o Select mission and design alternatives to eliminate or control risks of performance loss, program delay, or cost overruns
- o Design auxiliary missions to allow operations and support as independent as possible from basic space station functions. This might involve separate C3 capabilities, data transmission through links with space station transparency, or various levels of system/experiment autonomy.

Examples of subsystems or configurations that can lower system interference hazards and program risks are rescue vehicles, TMS, personnel transporters, tethered systems and specialized free flyers.





## FOREIGN PARTICIPATION

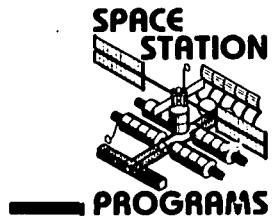
- TO DEVELOP THE SPACE STATION AS AN INTERNATIONAL VENTURE, PROMOTE INCLUSION OF OTHER NATIONS' DESIRED MISSIONS, TECHNOLOGIES, AND DESIGNS
- OTHER NATIONS' MAXIMUM INTEREST AND LEVEL OF CONTRIBUTIONS SHOULD EMPHASIZE
  - A COUNTRY'S LEADING TECHNOLOGIES
  - PARTS/MATERIALS/PROCESSES/DESIGNS PATENTED OR PROPRIETARY
  - PRIORITY DEVELOPMENTS TO COMMIT RESOURCES AND FORGE ADVANCES
    - LOOKING FOR BREAKTHROUGH
    - DEVELOP NEW CAPABILITIES AND MARKETS
- MINIMIZE INTERFERENCE BETWEEN BASIC SPACE STATION AND AUXILIARY MISSIONS
  - MINIMIZE SCHEDULE, COST, AND DESIGN UNCERTAINTIES
  - INDEPENDENTLY OPERABLE AND SUPPORTABLE
  - SEPARABLE, REMOVEABLE, REPLACEABLE
  - INTERNALLY FAILSAFE; UNABLE TO CAUSE CRITICAL FAILURES IN STATION

RE-SUPPLY AND CREW ROTATION

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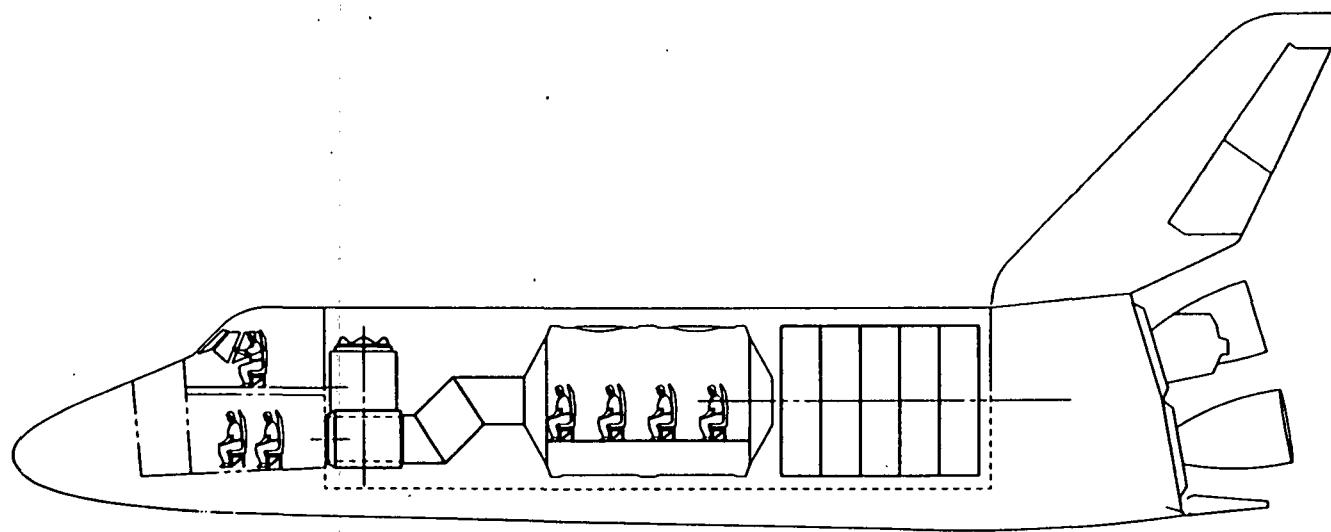
With the number of personnel on a space station increasing as missions become more complex and demanding, a need arises for a personnel transportation vehicle. On the next page is shown a modification of the space lab module which now can carry 12 people. With four more people in the shuttle, it allows transport of 16 people. Required modifications to the space lab module will be substantial: all racks removed, floors strengthened, and ECLSS upgraded, just to name a few. The expendable supplies for a 16 man crew for 6 months weigh 27,000 lbs and occupy 2400 cu ft. Both the crew and expendable supplies can be carried in a single shuttle launch, if the Spacelab axis tunnel is shortened as shown. However, this would be a specific non strategic subsystem to the overall space station system, responsibility for which could be given to the space lab manufacturers (Germany).





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## RE-SUPPLY AND CREW ROTATION



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## 10-PERSON RESCUE VEHICLE

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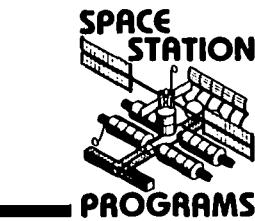
We have studies a number of rescue vehicle designs to take personnel off disabled craft.

A 10-person rescue vehicle is shown in the figure. This vehicle would be stored in space and delivered to any orbit by an OTV. It could pick up the disabled crew and deposit them on earth.

A number of scenarios exist for this type of mission. It also is an ideal system to be separated from the space station itself and thus is ideal for development by ESA. This would give the Europeans responsibility for an overall system, without controlling influence over the space station.

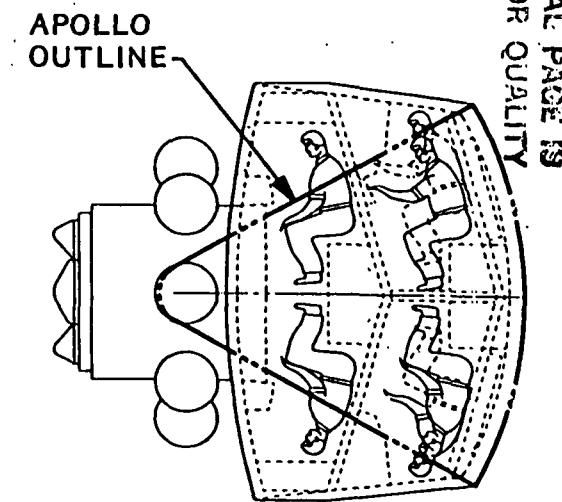
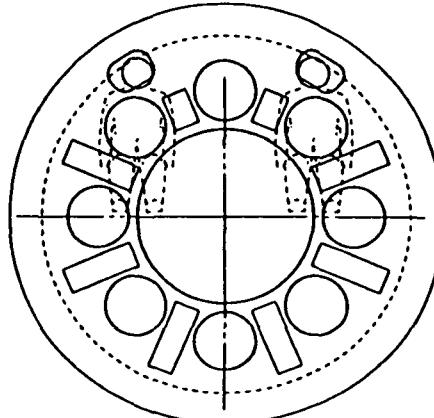
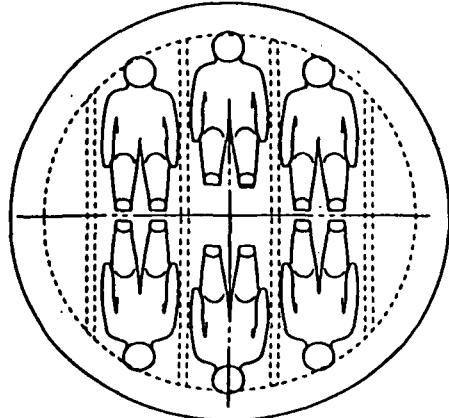
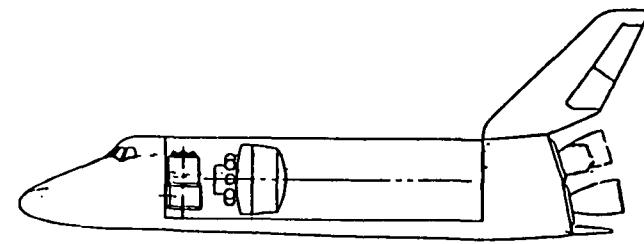
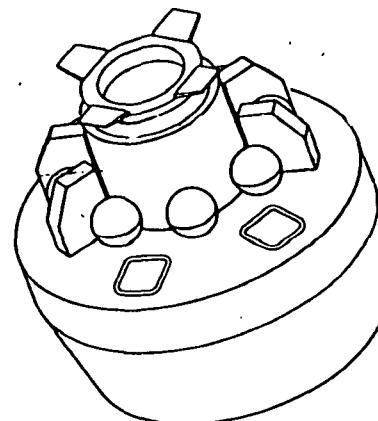
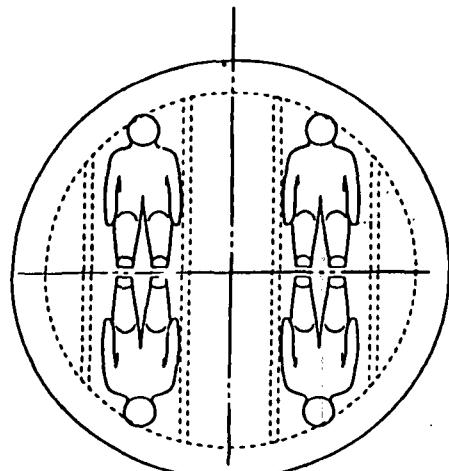
The issue of rescue vehicles has been discussed with GTS (London). Concepts of a one way return rescue vehicle stored in space and ready for action were covered also.





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## 10-PERSON RESCUE VEHICLE

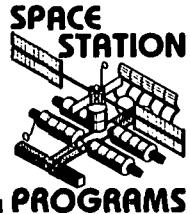


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The concept shown here exemplifies how a foreign country could participate in the space station program. In this instance, Spar Corporation of Canada would design and develop advanced versions of the remote manipulator system. Such isolatable sub-system components can be integrated as single items requiring only basic interface controls to ensure compatibility with station requirements. Other payload handling and special purpose equipment readily can be detached from the main space staton stream and also be developed in Canada.

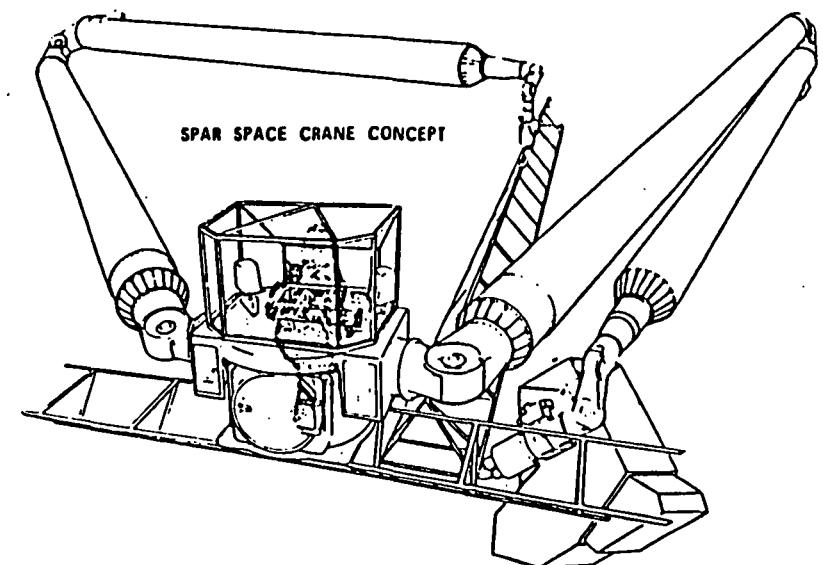
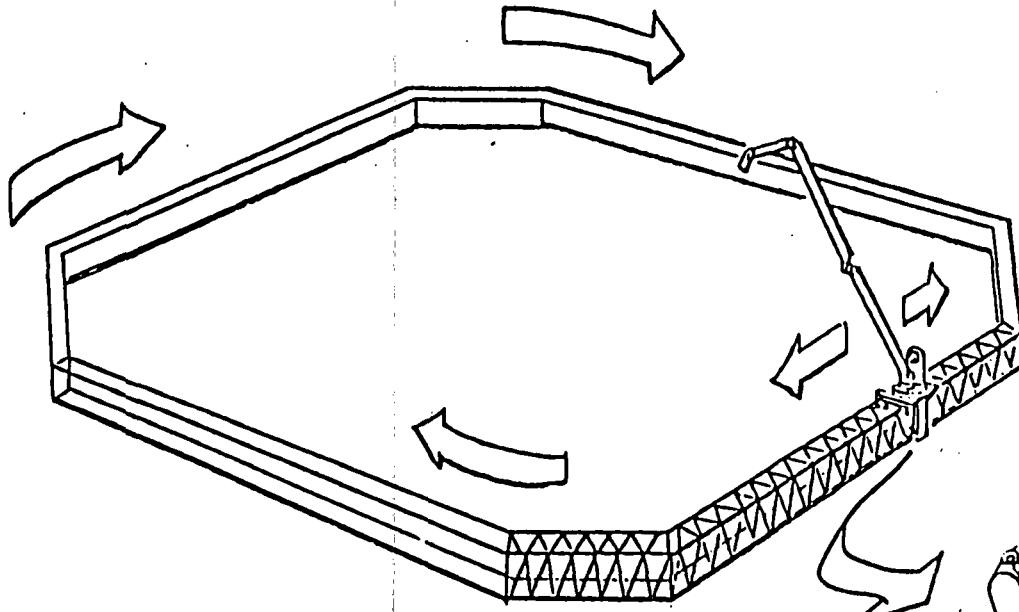




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## TETHERED CONCEPTS

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The figure shows a tethered concept for a tank farm. However, it also would be feasible to tether a material-processing plant to take advantage of the low g rates.

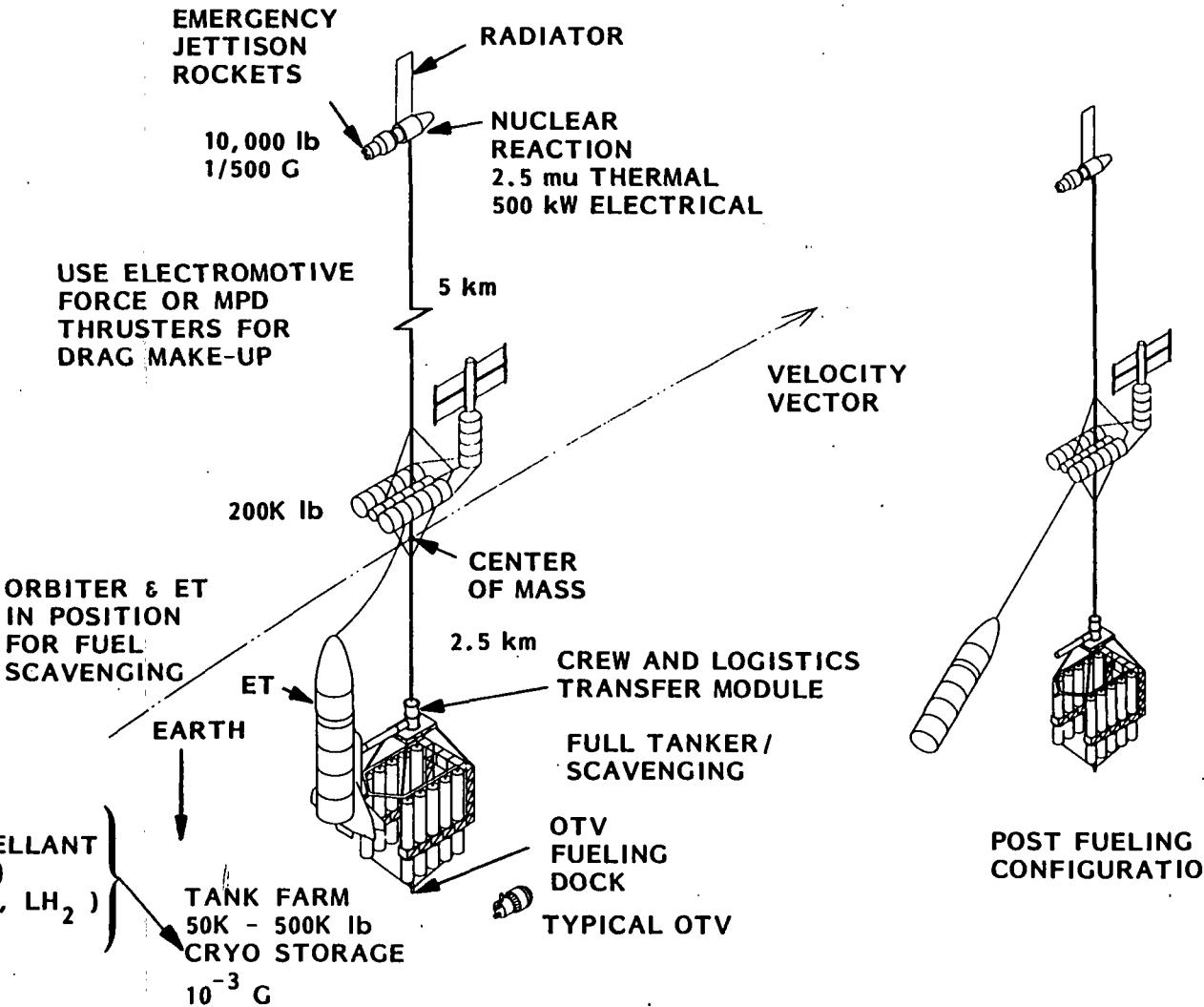
The Italians have spent a lot of time and effort on the tether concept. This type of subsystem would be ideally suited for design and fabrication by Italy. This would include the tether and mechanisms.

A joint NASA-Italian shuttle flight will test the tether concept in 1987.



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## TETHER CONCEPT



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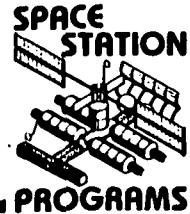
## ROBOTICS

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Japan now is considered one of the most advanced countries in robotics. They would be perfectly suited to design and fabricate robots for transportation, repair and maintenance, inspection, and other tasks.

Robot system advances for such tasks require development and application of artificial intelligence capabilities. The Japanese now are pressing development of artificial intelligence.





## ROBOTICS

- INTERNAL AND EXTERNAL INSPECTION OF THE MAIN VEHICLE AND REMOTE VEHICLES
- REPAIR AND MAINTENANCE FUNCTIONS
- TRANSPORTATION OF PERSONNEL, SUPPLIES, RAW MATERIAL, AND FINISHED PRODUCTS TO AND FROM FREE-FLYERS AND TETHERED VEHICLES

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